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Abundance, Age, Size, Sex and Coded Wire Tag Recoveries for Chinook Salmon Escapements of Atnarko River, 1984-1986

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ABUNDANCE, AGE, SIZE, SEX AND CODED WIRE TAG RECOVERIES FOR CHINOOK SALMON ESCAPEMENTS OF ATNARKO RIVER, 1984 - 1986

by

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ABSTRACT

Andrew, J.H., G.D. Sutherland and T.M. Webb. 1988. Abundance, age, size, sex and coded wire tag recoveries for chinook salmon escapements of Atnarko River, 1984 - 1986. Can. MS Rep. Fish. Aquat. Sci. 2014: 87 p.

This report describes chinook salmon (*Oncorhynchus tshawytscha*) escapement estimation programs on the Atnarko River on the central coast of British Columbia from 1984 to 1986. Escapement was estimated by an extended Jolly-Seber method using tagged carcasses and the Petersen method using live tagging. The Petersen escapement estimate for 1986 was 14,018 spawners, and the Jolly-Seber escapement estimates were 6,762 in 1984, 9,734 in 1985, and 3,530 in 1986. These estimates were compared to the results of other methods, including expanded fisheries officer counts, broodstock catch per gillnet set and tower counts. Based on a comparison between these methods, we argue that the Jolly-Seber estimates were biased downwards substantially, most likely due to incomplete mixing of tagged and untagged carcasses.

Spawners ranged in age from 2_1 to 6_2. Age classes 4 and 5 predominated. Hatchery contributions to the 1985 escapements were 0.66% and 1.34%, respectively, as estimated from the recovery of adipose clipped carcasses and the decoding of coded wire tags.

Key words: Atnarko, chinook, keystream, escapement, coded wire tags, age composition, hatchery, live tagging, carcass tagging.

RÉSUMÉ

Andrew, J.H., G.D. Sutherland and T.M. Webb. 1988. Abundance, age, size, sex and coded wire tag recoveries for chinook salmon escapements of Atnarko River, 1984 - 1986. Can. MS Rep. Fish. Aquat. Sci. 2014: 87 p.

Le présent rapport traite des programmes d'estimation des remontées de saumon quinnat (Oncorhynchus tshawytscha) dans la rivière Atnarko, située dans la partie centrale de la côte de la Colombie-Britannique, de 1984 à 1986. Les échappées ont été estimées à l'aide d'une méthode Jolly- Seber modifiée faisant appel aux carcasses portant des étiquettes et de la méthode Petersen, par marquage de poissons vivants. Les valeurs estimées des échappées ont été de 14,018 géniteurs en 1986, par la méthode Petersen, et de 6,792 en 1984, de 9,734 en 1985 et de 3,530 en 1986, par la méthode Jolly-Seber. Ces estimations ont été comparées à celles obtenues par d'autres méthodes dont, notamment, les dénombrements élargis des agents de pêches, les captures de géniteurs par jeu de filets maillants et les dénombrements directs. Après comparaison des résultats des méthodes utilisées, les auteurs ont conclu que les estimations de la méthode Jolly-Seber étaient assez fortement biaisées à la baisse, probablement à cause d'un mélange insuffisant des carcasses marquées.

L'âge des géniteurs variait de 2_1 à 6_2 et les classes d'âge 4 et 5 dominaient. Les apports de pisciculture aux échappées de 1985 et 1986 ont été, respectivement, de 0.66% et 1.34%; ces valeurs ont été estimées à partir des carcasses de poissons à nageoire adipeuse coupée récupérées et du décodage des étiquettes en fils codés.

Mots clés: Atnarko, quinnat, cours d'eau principal, échappée, étiquettes en fils codés, composition par âges, pisciculture, marquage de poissons vivants, carcasses marquées.

INTRODUCTION

Chinook (Oncorhynchus tshawytscha) are a highly prized salmon species for both the sport and commercial fisheries in coastal British Columbia. Over the last few years, declines in chinook stocks have prompted management efforts to protect chinook populations and enhance and rebuild certain stocks.

In 1984, the Department of Fisheries and Oceans (DFO) initiated a program to monitor British Columbia chinook stocks in a number of "key streams", representative of specific Statistical Areas. The objectives of the key stream program and Atnarko sampling were to:

- o accurately estimate chinook escapement;
- o estimate contributions of hatchery and natural production to that escapement; and
- o develop a biological database of age, size, and sex composition of the escapement as a basis for more detailed stock/recruit analyses.

Streams were chosen for the key stream program based on the following criteria: the presence of a relatively large chinook escapement, the presence of a hatchery, accessibility for field sampling, feasibility of fence operations, and geographic distribution with respect to other key streams such that different areas of the coast would be represented in the program.

One of the selected key streams is the Atnarko River, a major tributary of the Bella Coola River. The Bella Coola drainage system supports one of the largest chinook salmon stocks in North America. Chinook escapements to the Atnarko River were enumerated by the extended Jolly-Seber tag-recapture method (Parker 1968) using tagged carcasses (1984, 1985, and 1986) as well as the Petersen method using tagging of live fish (1986).

Coded wire tagged fry have been released to the Atnarko River since 1978 to assess the contribution of hatchery stocks to the river escapement and to determine harvest rates for Atnarko chinook in ocean fisheries. The Snootli Creek Hatchery was constructed in 1978 to increase the size of chinook escapement to the Atnarko River.

The purpose of this report is to review Atnarko River chinook escapement enumeration and coded wire tag programs from 1984 to 1986. Assumptions for the Jolly-Seber and Petersen methods and tests for biases caused by violations of these assumptions are described in the methods section. The results section presents the estimates of population enumeration by each method, tests for biases in tagging and recovery, and the results of CWT studies. The enumeration results are then discussed with respect to other enumeration programs that were conducted on the Atnarko River from 1984 to 1986: fishery officer estimates of escapement based on live counts, estimates based on tower counts of live fish, and estimates based on the catch per effort in gillnets used by the Snootli Creek Hatchery staff. (The results of these alternative

enumeration programs are presented in appendices.) Problems in using multiple mark-recapture methods on carcasses in this system are discussed, and conclusions are made regarding future studies.

To avoid confusion in terminology relating to tagging and marking, "live tagging" as used in this report refers to tagging of live fish with spaghetti tags, "carcass tagging" refers to tags applied to carcasses, "punching" refers to secondary marking of live chinook by punching holes in the operculum, and "marking" refers to marking of chinook juveniles with coded wire tags and adipose fin clips.

STUDY AREA

Estimates of chinook escapements to the Bella Coola drainage system range from 3,500 to 35,000 spawners, with an average of 18,000 (Manzon and Marshall 1980). The Atnarko River is the major contributor to this escapement (Hilland 1979). The Atnarko River is one of two main tributaries that drain into the Bella Coola River; the other major tributary is the Talchako River (Fig. 1).

The Atnarko River is a clear water lake-fed stream arising in the high plateau country east of the coastal mountains and drains a 2,440 sq. km. watershed which is within the boundaries of Tweedsmuir Provincial Park (Hilland 1979; Parker 1968). Due to the high snow melt and glacial influence, turbidity is extremely high in late spring and early summer. The main tributaries of the Atnarko River are Mosher Creek, Young Creek, Hotnarko River, Hunlen Creek, and South Atnarko River (Department of Fisheries and Oceans 1987). Further upstream, the Atnarko River is fed by Charlotte Lake and the Lonesome Lakes chain.

Chinook spawn throughout the Atnarko River (Department of Fisheries and Oceans 1987), entering the Bella Coola River in the spring and summer (mid-April to early August) while water levels are high, and holding in the deeper pools of the system until spawning from mid-August to mid-October (Department of Fisheries and Oceans 1987, Slaney 1986). Spawning areas are concentrated in the areas between the Hotnarko River confluence and the old townsite of Atnarko on the upper river, and between Flat Rock and the Fisheries Pool on the lower river (Fig. 1; Anon. 1984). Holding pools occur throughout the system; these include the Fisheries, Smokehouse, Put In, Belarko, and Elbow pools (Figure 1). In addition, there are numerous smaller pools in Mosher Canyon and upstream from the rapids at the mouth of Young Creek (Whelen and Slaney 1985). There is some indication from coded wire tag studies that chinook spawning upstream of the Young Creek rapids (in this report referred to as the "upper river") are a separate sub-population from those spawning downstream of the rapids ("lower river"; R. Hilland, Manager, Snootli Creek Hatchery, Box 95, Bella Coola, B.C., V0T 1C0, pers. comm., 1988).

In addition to chinook, the Atnarko River supports coho, pink, sockeye and chum salmon (*Oncorhynchus kisutch*, *O. gorbuscha*, *O. nerka*, and *O. keta*, respectively), as well as steelhead (*Salmo gairdneri*), cutthroat (*Salmo clarki*) trout, and Dolly Varden char (*Salvelinus malma*) (Whelen and Slaney 1985). Pink salmon spawn throughout the river in nearly equal abundance in both the upper and lower sections.

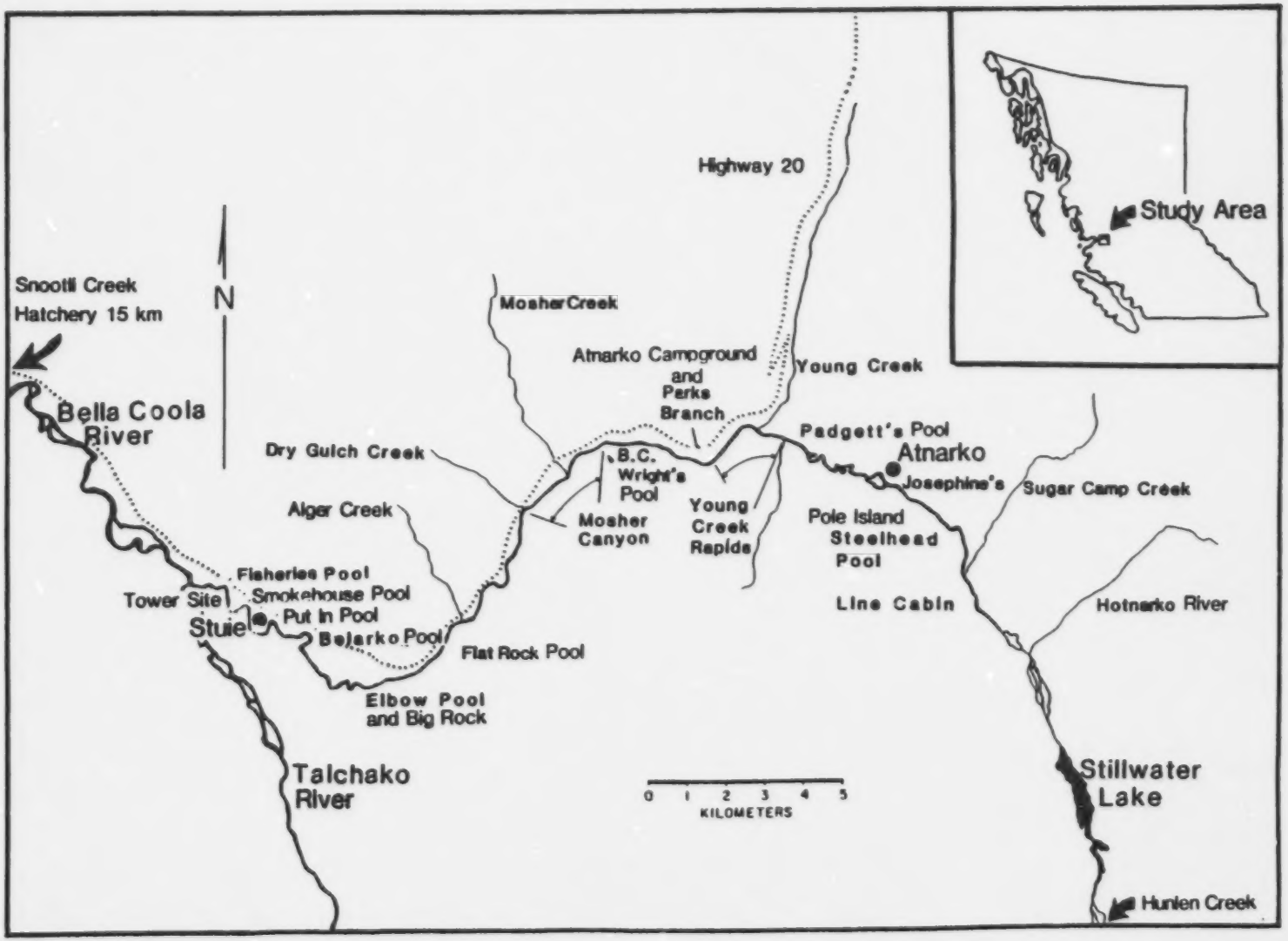

Figure 1. Map of the Atnarko River study area, 1984-1986.

A hatchery located on Snootli Creek on the lower Bella Coola River 13 km east of Bella Coola adjacent to Highway 20 was built in 1978 and became operational in 1979 to enhance production of chinook salmon to the Atnarko in 1981.

Fisheries on the Atnarko River chinook stocks include sport and Indian food fisheries. There are no commercial fisheries within the boundaries of Tweedsmuir Park. The Atnarko sport fisheries are closed upstream of Young Creek at all times; closed from July 15 to October 15 to protect chinook spawners; closed for roe from May 1; and open from the Atnarko River mouth to Stuie for coho salmon on September 15 (R. Hilland, pers. comm., 1988). There is a small Indian Food Fishery (IFF) at Stuie that targets sockeye salmon, and a larger fishery at the Bella Coola Indian Reserve downstream of the Atnarko River to near the mouth of the Bella Coola River. In the latter food fishery it is estimated that approximately 1500 Atnarko chinook are taken per year (R. Hilland, pers. comm., 1988).

Access to the Atnarko River may be obtained at Fisheries Pool, Belarko, the Parks Branch, Josephine's, and the Line Cabin (Fig. 1). Access to areas upstream of the Line Cabin is by hiking trails. Human development along the Atnarko River includes two abandoned homesteads at Belarko and Josephine's, and the Tweedsmuir Lodge at Stuie which was formerly an old homestead (R. Hilland, pers. comm., 1988).

METHODS

In each year from 1984 to 1986, the Atnarko study area was subdivided into reaches (Table 1). Survey reaches varied in length between years for the following reasons:

1) the 1985 and 1986 studies had more complete coverage of the river than in 1984;

2) the portion of the river from Flatrock Pool to the Atnarko Campground (see Fig. 1) was not surveyed in 1984; and

3) more care was taken in sampling side channels in 1986 (Slaney 1986).

Fast-flowing sections of the river (principally the Young Creek and Mosher Canyon rapids, which represent approximately 8% of the study area (Fig. 1)), were not regularly surveyed in any year as salmon spawning habitat was limited due to high stream gradient and limited spawning gravel (Whelen and Slaney 1985).

POPULATION ESTIMATION

Two methods of population estimation were used in this study: Petersen and Jolly-Seber methods. Details of their application in this study are described below, and summarized in Table 2.

Table 1. Sampling reaches for chinook salmon tagging and recovery in the Atnarko River, 1984 - 1986.

Year	River area	Sampling reach	Location[a]
1984	Upper	1	Hotnarko River - Young Creek
	Lower	2	Flatrock Pool - Fisheries Pool
1985	Upper	1	Stillwater Lake outflow - Pole Island
		2	Pole Island - Parks Branch
	Lower	3	Parks Branch - Big Rock
		4	Big Rock - Talchako River confluence
1986 (Sept.16- Sept.25)	Upper	1	Stillwater Lake outflow - Steelhead Pool
		2	Steelhead Pool - Padgett's Pool
	Lower	3	Parks Branch - B.C. Wright's Pool and Flatrock Pool - Elbow Pool
		4	Elbow Pool - Fisheries Pool
1986 (Sept.27- Oct.16)	Upper	1	Stillwater Lake outflow - Line Cabin
		2	Line Cabin - Josephine's Pool
		3	Josephine's Pool - Padgett's Pool and Parks Branch - B.C. Wright's Pool
	Lower	4	Flat Rock - Elbow Pool
		5	Elbow Pool - Fisheries Pool

[a] See Figure 1.

Table 2. Summary of methods for Atnarko River chinook salmon enumeration programs, 1984 - 1986.

Item	Method or materials[a]		
	1984[b]	1985[c]	1986[d]
Population enumeration	Jolly-Seber, sexes pooled, areas separate, carcasses replaced	Jolly-Seber, sexes separate, areas separate, carcasses not replaced	Petersen, sexes separate, areas separate; Jolly-Seber, sexes separate, areas separate, carcasses not replaced
Tagging	Carcass tags, not numbered	Carcass tags, color coded	Spaghetti tags, numbered; carcass tags, numbered
Secondary marks	None	None	Opercular punches
Recovery	Foot surveys	Foot, boat, and snorkel surveys; two carcass weirs	Foot, boat and snorkel surveys
CWT tagging		Releases in 1981 and 1982, adipose-clipped	Releases in 1981 to 1985, adipose-clipped
CWT recovery		Heads from adipose-clipped fish from DR	Heads from adipose-clipped fish from T, DR
Biological and physical sampling			
Sex	T, DR	T, DR	T, DR, IFF
Age		DR	IFF
POHL[e]		DR	DR, IFF
Spawning success		DR	DR
Water level	Water Survey of Canada	Water Survey of Canada	Water Survey of Canada
Water temperature			Hand-held and max/min thermometers

[a] T = tagging sample; DR = dead recovery sample; IFF = Indian food fishery sample.
[b] Data were collected by Bella Coola Biological Services.
[c] Data were collected by Aquatic Resources Ltd.
[d] Data were collected by Aquatic Resources Ltd. and Bella Coola Indian food fishery samplers.
[e] POHL = postorbital-hypural length.

Petersen Method

Population Stratification

In 1986, chinook were enumerated by Petersen estimate using live tagging of returning adults on the spawning grounds and recovery of tags from carcasses following spawning. There are four possible ways of stratifying the tagging and dead recovery data to produce escapement estimates:

1) sexes and areas (upper and lower river areas) pooled;

2) sexes separate with areas pooled;

4) sexes pooled with areas separate; and

3) sexes separate and areas separate.

Separate Petersen estimates can be calculated for each stratum and then summed to obtain an estimate of the whole population. By segregating the data into separate population strata, biases caused by factors which may affect the strata at different rates may be circumvented. The main factors of concern are rates of tag application, recovery of carcasses, and tag loss.

These factors may affect males, females and jacks at different rates since sexes can be subject to differential catchability for tagging, differential washout rates following spawning (affecting recovery rate), and different behavioural interactions that affect tag loss. Stratifying by sex would thus seem to be advisable.

There is evidence of two sub-populations in the Atnarko River that spawn in the upper and lower portions of the river. Coded wire tagged fry from upper river brood stock return to the upper river more frequently than to the lower river to spawn. In addition, the proportion of white flesh-coloured chinook in the upper river is greater than in the lower river (R. Hilland, pers. comm., 1988). If the spawners in the upper and lower rivers do not mix following tagging, forming two distinct groups for the purposes of enumeration, then again there is a potential of bias if tagging or dead recovery rates and effort are not identical.

Due to the likelihood of factors affecting sexes and areas at different rates, Petersen estimates were stratified by sex and area in this study.

Potential Biases

Within a stratum, Petersen estimates are potentially biased by violation of a number of assumptions. Seven of these assumptions, as modified from Ricker (1975, p.81-82) are presented below along with the consequences of violating them.

Tests used to determine whether biases were acting in this study are given below with respect to sex and area stratification of the Petersen estimate. Other biases caused by methods of tagging, recovery, age determination, etc. are discussed in subsequent sections.

1) Tags are consistently applied in proportion to the available population and/or the distribution of recovery effort is proportional to the number of fish present in different river reaches and/or tagged fish become randomly mixed with untagged fish.

To obtain an accurate Petersen estimate, it is important to apply and/or recover tags in proportion to the available population. It is not possible to test whether tagging and dead recovery were conducted on a consistent proportion of the population because there is no independent measure of the numbers of fish available for tagging and dead recovery, or of the timing of the migration or of the termination of spawning apart from the tagging and recovery data. However, this is an important problem since it affects the representativeness of sampling.

It is not possible to statistically test the extent of mixing of tagged and untagged fish using the data from this study, but movements of tagged fish are indicated by the location of recovery relative to the location of tagging (if tags are numbered). Tagging and recovery locations were grouped into river reaches to facilitate this comparison.

2) There is a negligible influx of spawners after the conclusion of tagging.

An influx of spawners following tagging could cause the Petersen calculations to overestimate or underestimate the true population depending on how they mixed with tagged fish. Testing this assumption would require tower counts of fish migrating into the river after tagging was completed; these data were not available.

3) Tagged fish suffer the same natural mortality as untagged fish.

Mortality due to tagging procedures cause Petersen calculations to overestimate the number of effective spawners. Mortality due to tagging may be indicated by reduced spawning success among tagged fish in the dead recovery. Tests for this bias are described in the recovery methods section.

4) There is no tag loss.

A high incidence of tag loss will cause Petersen calculations to overestimate the true population. Tag loss was determined by comparing recoveries of live tags and expected recoveries of live tags (based on opercular punch holes corrected for the release of tagged and not punched as well as punched and not tagged fish). The test for potential bias due to differential tag loss by sex is described in the tagging methods section. Petersen estimates were made using tag recoveries corrected for tag loss.

5) All tags are recognized and reported on recovery after the conclusion of tagging.

In this study, no repitches were conducted to reexamine carcasses for missed tags and secondary marks, therefore it was not possible to evaluate tag recognition.

6) Recovery efforts are made on the same population as was tagged.

Dead recovery from a population other than the tagged population will cause Petersen calculations to overestimate the true population. Indications that tagging and recovery were conducted on different populations would be different age frequency and length frequency distributions among the two samples. Since no sampling program for age or length data was conducted during live tagging in 1986, it was not possible to test for this potential source of bias.

7) There is adequate sampling to obtain a tag recovery rate which provides an accurate and precise population estimate.

A small number of tag recoveries in a stratum will cause Petersen estimates to have low precision. Petersen estimates are generally more reliable if a high proportion of the tagged fish are recovered in each stratum (Ricker 1975). In the absence of other sources of bias, approximately 25 to 75 recaptures will produce population estimates within 25% of the true population size, with 95% confidence, for populations of 10^2 to 10^9 (Ricker 1975). Confidence intervals for the estimates were calculated as described below.

Calculations

The Petersen estimate of each stratum was calculated as follows (Chapman's formula, cited in Ricker 1975, p.78):

$$\text{Petersen estimate} = (\text{total pitched} + 1) \times \frac{(\text{total tags available} + 1)}{(\text{total tags recovered} + 1)}$$

Separate Petersen estimates were made for each sex and area. Petersen estimates were not calculated for jacks as no jacks were recovered in the dead pitch. Population estimates for each stratum were summed to obtain a total population estimate for males and females in 1986.

Confidence intervals for the population estimate of each stratum were calculated as follows:

$$VAR_{m,up} = \frac{(PE_{m,up})^2 \, (TA_{m,up} - TR_{m,up})}{(TA_{m,up} + 1) \, (TR_{m,up} + 2)} \quad \text{(Ricker 1975, p.78)}$$

$$\text{Upper and lower 95\% confidence limits of } PE_{m,up} = PE_{m,up} \pm 1.96 \sqrt{(VAR_{m,up})}$$

Confidence limits for the total population estimate was calculated by summing the variances of strata as follows:

$$VARt = VARm,up + VARm,low + VARf,up + VARf,low$$

and applying this figure in the calculation of the 95% confidence interval for the total population estimate as follows:

$$\text{Upper and lower 95\% confidence limits of PEt} = PEt \pm 1.96 \sqrt{(VARt)}$$

where VAR = variance of the population estimate
PE = Petersen estimate
TA = tags (and punches) applied
TR = tag (and punch or tag scar) recovery
m,up = male, upper river stratum
m,low = male, lower river stratum
f,up = female, upper river stratum
f,low = female, lower river stratum
t = total males and females.

Strays

In this study, tagged fish moving through the Young Creek Rapids were considered to be strays. "Straying" from the upper to the lower river was probably due largely to passive drift of moribund fish. Ideally, tagged strays could be recognized by their tag numbers. Unfortunately, this was frequently not the case due to tag loss.

For purposes of the Petersen calculation, an estimate of tagged strays was made using the number of tagged strays increased by the dead recovery rate. For purposes of this calculation, the dead recovery rate was calculated using areas pooled and sexes separate strata. The number of punched fish available in each of the upper and lower river dead recovery programs was calculated by taking the number of punched fish in each location and subtracting the number of punched strays that moved to the opposite portion of the river and adding the number of punched strays that arrived from the opposite location. The calculations were performed as follows:

$$\text{Tagged strays from lower river} = \text{Number tagged strays from lower river in dead pitch} \times \frac{1}{\text{Dead recovery rate}}$$

where

$$\text{Dead recovery rate} = \frac{\text{Total recovered}}{\text{Total population}}$$

and

Tags available = Tags applied in lower river - Tags removed in eggtake
+ Tagged strays from upper to lower river - Tagged strays from lower to upper river

The Petersen calculation was performed using the calculated tags available in the Petersen equation given above. This approach gives an estimate of the population of carcasses (as opposed to live fish).

Jolly-Seber Method

Chinook were enumerated by Jolly-Seber estimate using multiple carcass tagging and recapture in all three years of the study. The method used was based on that developed by Jolly (1965) and Seber (1965) and is described widely (e.g. Ricker 1975). The approach requires at least four sampling occasions. On each occasion, sampled fish are tagged with a tag specific to that occasion (some or all are tagged), recoveries from earlier taggings are noted, and tagged fish may or may not be returned to the population. Untagged sampled fish which are then not tagged may be returned to the population or may be removed. This pattern of tagging, sampling, and recovering forms the basis for an estimate of the abundance on each occasion of sampling except the last occasion, and of the rates of immigration and emigration/mortality.

This basic Jolly-Seber method was extended to estimate the total immigration into the population prior to the first sampling period and between each sampling interval. The immigration was then summed to form an estimate of the total immigration to the population and was used as the estimate of the total escapement. This extension to the Jolly-Seber method was originally derived by Dr. G.J. Paulik of the University of Washington in Seattle (Parker 1968). Webb (1988) has described a more complete history of the method and an analysis of some sources of bias in its use.

Population Stratification

For the same reasons described for the Petersen method, segregating the data into separate population strata circumvents biases caused by factors which may affect the strata at different rates. Due to the likelihood of factors affecting sexes and river areas at different rates, Jolly-Seber estimates were stratified by sex and area in this study. These factors include differential catchability of sexes for tagging, differential washout rates, and different behaviours of carcasses as well as greater mixing of carcasses within river areas than between areas.

Potential Biases

In general, many of the potential biases of the Petersen method described above also apply to the Jolly-Seber method. As the Jolly-Seber method employs carcass tagging, the resulting estimate may be biased if

the six assumptions, as modified from Webb (1988) are violated. Tests used to determine whether biases were acting in this study are presented below and discussed with respect to sex and area stratification of the Jolly-Seber estimate.

1) The whole population is available for sampling.

The Jolly-Seber method may underestimate the population if one or more sub-populations is washed out of the system prior to tagging. This may occur in a number of ways. Carcasses from particular areas can be washed out of the system without moving to the banks where they are available for tagging, or washed into deep pools where they are not available for sampling. Certain groups (especially males) may be washed out of the system in a moribund state and not die until after they have left the study area. Whereas female salmon normally hold over their redds after spawning and tend to move into shallow quiet water as they weaken (a behaviour that makes them more recoverable than males), males make a lesser attempt to hold their position and are washed out of the spawning stream by the current. A higher recoverability of females in spawning ground dead pitches has also been noted for sockeye (Petersen 1954), pinks (Ward 1959), and coho (Eames and Hino 1981 and Eames et al. 1981). To test whether this assumption was violated, recoveries at the carcass weir used in 1985 were examined for sex (described in the recovery methods section).

2) Tagged carcasses are representative of the population.

Tagged carcass recoveries will not be representative of the population if they do not mix completely with untagged ones, in which case the Jolly-Seber method may overestimate or underestimate the population. The thoroughness of mixing depends on how tagged carcasses are replaced into the river and whether they behave in a similar manner to untagged carcasses once replaced. Following tagging, carcasses may be replaced in the river at either the same spot from which they were removed or in a flowing part of the stream. When carcasses are not well mixed as is frequently the case, the population will be effectively separated into two groups (with some movement between them): those carcasses which remain in shallow water and those that are washed more rapidly through the system. Carcasses placed in flowing parts of the stream are more likely to be mixed among other carcasses. The assumption that tagged and untagged carcasses behave in a similar manner is addressed in the next point. It is not possible to statistically test the assumption of mixing with the data from this study. Comparisons are made of tagging and recovery reaches of tagged fish. Further data that would provide an indication of the extent of mixing would be more precise information on tagging and recovery location such as shallow water versus deep pool locations.

3) Tagged carcasses behave in a similar manner to untagged carcasses with respect to buoyancy, visibility, and decomposition.

Differences in tag visibility could cause preferential sampling of tagged carcasses, and result in an underestimate of the population. If tagged carcasses are not from an external source, it is not likely that buoyancy and decomposition would be important factors causing

differential behaviour of tagged and untagged carcasses unless tagged carcasses become bloated with air during handling. It is not possible to test the assumption of similar visibility between tagged and untagged carcasses with the data from this study. The assumption of similar buoyancy and decomposition of tagged and untagged carcasses was tested by comparing the tag recovery rate in the dead recovery and on the carcass weirs in 1985 (see recovery methods section).

4) Catchability of carcasses does not vary with time after death (age).

As carcasses age, they decompose and become less susceptible to sampling. If tag status and mortality are not correlated, then Seber (1982) indicated that Jolly-Seber estimates will not be seriously biased. It is not possible to test this assumption with data from this study.

5) Catchability of carcasses does not vary with sex.

If catchability of carcasses varies with sex, unstratified Jolly-Seber estimates can be under- or overestimates of the population size. Differential catchability with sex could result from different washout rates of male and female carcasses. The solution to variable catchability with sex would be to stratify the Jolly-Seber estimate by sex. The assumption of similar catchability of male and female carcasses was tested using carcass weir data from 1985 (see recovery methods section).

6) There are an adequate number of recaptures in each sampling period to produce an accurate and precise population estimate.

A small number of recoveries in a stratum will cause Jolly-Seber estimates to have low precision. Confidence intervals for the estimates were calculated as described below.

Calculations

In each of the years from 1984 to 1986, the Jolly-Seber estimate of each sex and river area stratum was calculated as described in Webb (1988). Population estimates for each stratum were summed to obtain a total population estimate for each year.

Confidence limits for Jolly-Seber escapement estimates were derived using a Monte Carlo model to replicate the Jolly-Seber tag-recapture experiments for each stratum (Webb 1988). These confidence limits assume the underlying assumptions of the Jolly-Seber method are not violated; if violated, the limits may be too narrow. Approximate 95% confidence limits for the total population estimates were calculated by summing the variances of the strata then calculating the limits for the total estimate as follows:

Confidence Interval of stratum (CI range) = Upper 95% limit - Lower 95% limit

$$\text{Variance of stratum} \approx \frac{(\text{CI range})^2}{(2 \times 1.96)}$$

$$\text{Total variance of strata} = \Sigma \text{ Variance of strata}$$

$$95\% \text{ confidence limits of total estimate} = \text{Total estimate} \pm 1.96 \sqrt{(\text{Total variance of strata})}$$

Strays

Strays could be calculated for the 1986 Jolly-Seber only, when carcass tags were numbered. However, as the number of carcasses "straying" from the upper to the lower river was equal to the number from the lower to the upper river (all sexes n=5), it is likely that at least "stray" tag recoveries may have been due to data coding errors; hence no corrections for straying were made in 1986. Some carcass movement from the upper to lower river areas was expected, but not from the lower to upper river.

TAGGING

Petersen Method - Live Tagging

Live tagging was conducted in conjunction with Snootli Creek Hatchery broodstock collection from September 2 to 15, 1986. The tagging schedule and geographic distribution of sampling are shown in Appendix 1. Based on preseason expectations of escapement, an overall tagging target of 1,500 was established. Tagging targets of 700 in the upper Atnarko and 800 in the lower Atnarko were determined based on a September 2 helicopter reconnaissance flight and experience from previous years.

Chinook were captured for the broodstock eggtake and live tagging on the spawning grounds prior to spawning. Most of the ripe fish captured were used by the hatchery for broodstock; fish that were not required by the hatchery were live tagged and released. As the tagging program progressed, some tagged fish were recaptured. Previously tagged chinook not needed for the egg take (e.g. males, unripe females, and/or kelt females) were released, but some tagged ripe females were taken for broodstock. Corrections were made in the Petersen calculations for tagged females that were removed for broodstock. Milt was collected for fertilization of hatchery broodstock from some tagged and untagged males before their release.

Chinook were captured for the eggtake and live tagging using a 21.3 m tangle gillnet with 23 cm stretched mesh. When gillnets were beached, chinook were "tailed" (tied around the caudal peduncle with a braided polyethylene rope) to facilitate handling and to prevent injury to the fish. The fish were held in shallow water (without anaesthetic) with their tails above the water surface from one to five minutes until tagging and other procedures were completed. The date, capture reach, tag number, sex, and presence of an adipose clip were recorded before each fish was released to the river. Males were considered to be jacks if

their length was less than or equal to 50 cm. Tags were applied to virtually all fish that were captured, with the exception of ones taken for broodstock. However, fish that were drowned by being gilled or fish that were bleeding profusely from torn gill filaments were not tagged.

Biases in the size distribution of tagged fish relative to the population may have resulted from the large mesh size of the gillnet sampling gear, the sampling technique, or other causes. However, no length data were collected during the live tagging, hence tests of this potential bias were not possible.

Numbered spaghetti tags (30.5 cm long) were used for live tagging. Tags were knotted at the base of the posterior end of the dorsal fin such that the two ends were approximately 14 cm in length. A second mark was administered to most of the live-tagged fish (92.0%) by punching a 6 mm diameter hole in the operculum. Punch holes were administered to the left operculum using a standard paper hole punch. The purpose of opercular punches was to evaluate tag loss. However some tagged fish were released without punches and some punched fish were released without tags (see results section).

Potential bias in the Petersen estimate created by differential tag loss by sex was examined by using χ^2 tests to compare the observed tag recoveries and the expected tag recoveries.

Tag loss was calculated as follows:

$$\text{Tag loss} = \frac{\text{(Expected tag recoveries - actual tag recoveries)}}{\text{Expected tag recoveries}}$$

where

$$\text{Expected tag recoveries} = \text{Actual recoveries of tagged and punched fish} \times (1 - \text{Proportion of releases of punched and not tagged})$$

Tag recoveries were corrected for tag loss in the Petersen equation given above.

Jolly-Seber Method - Carcass Tagging

Carcass tagging was conducted from early September to late October in 1984, 1985, and 1986 (Table 3). The tagging schedule and geographic distribution of sampling are shown in Appendices 2 and 3. Crew sizes varied both within and between years; there were two to four crew members in 1984, four to twelve in 1985, and four in 1986 (Table 3). In 1984 and 1986, the enumeration studies were directed solely at chinook salmon. In 1985, a tag recovery program for pink salmon was carried out as part of the Canada-U.S. International tagging program in conjunction with the chinook program.

Table 3. Sampling dates and crew sizes for the chinook escapement Jolly-Seber enumeration studies on the Atnarko River, 1984-1986.

Sampling period	1984		1985		1986	
	Date	Crew size (persons)	Date	Crew size (persons)	Date	Crew size (persons)
1	Sept. 4-5	3	Sept.12-15	8	Sept.16-19	4
2	Sept. 7-8	3	Sept.16-19	8	Sept.21-25	4
3	Sept.10-11	2	Sept.20-23	8	Sept.28-2	4
4	Sept.13-14	2	Sept.24-27	8-12	Oct. 5-9	4
5	Sept.16-17	2	Sept.28-1	12	Oct. 12-16	4
6	Sept.19-20	2-3	Oct. 2-5	12	-	
7	Sept.22-23	3	Oct. 6-9	6	-	
8	Sept.25-26	3	Oct. 10-13	6	-	
9	Sept.28-29	4	Oct. 14-18	4	-	
10	Oct. 1-2	3	-		-	
11	Oct. 4-5	3	-		-	
12[a]	Oct. 21	3	-		-	

[a] Sampling of upper river area only.

In each year, carcass tagging was conducted as follows:

1984 Carcasses were tagged with painted, waterproof paper attached to a rubber band placed around the tail of each carcass. Different coloured tags were used in each sampling period.

1985 Carcasses were tagged with painted, electrical straps fastened around the caudal peduncle of the carcass. As in 1984, different coloured tags were used in each sampling period.

1986 Carcasses that were not already live-tagged were carcass-tagged on the right opercular plate with a numbered aluminum tag (Ketchum "Kurl Lock").

Following tagging of each carcass, it was placed as closely as possible to its original position. If the carcass had collected air during tagging procedures, it was held in place until the air escaped.

RECOVERY

Carcass and tag recovery procedures described below were used for the Jolly-Seber program. Carcass recovery for the Petersen estimate in 1986 was conducted concurrently with the Jolly-Seber carcass recovery. The recovery schedule and geographic distribution of recovery effort (number of fish sampled) are presented in Appendices 4 and 5.

Surveys for carcasses were carried out using a variety of techniques. Pools and fast-flowing stream areas were sampled by swimming and/or snorkelling, while shallow portions of the river, stream banks and logjams were searched by walking established paths and using curved fish pews and gaffs to probe for carcasses. In 1984, each crew member covered the same stretches of the river for the first eight sampling periods, and crews were rearranged in sampling period nine so that each crew member examined unfamiliar sections of the river. For the first two sampling periods in 1984, crews attempted to cover each side channel in heavily-braided areas, and for the remaining periods, crews remained together and stayed to the main channel or followed the channel that appeared to have the most spawning. In 1985 and 1986, crews attempted to follow the same paths on every sampling round.

In each year, the treatment of tagged and untagged recovered carcasses was as follows:

1984 Recovered carcasses that had been previously tagged, and untagged carcasses that were examined but not tagged (due to limitations of effort), were replaced in the population in the same stream position as they were recovered.

1985 Previously tagged carcasses were pitched from the river when recovered and untagged carcasses were either pitched from the river or were tagged and replaced.

1986 Previously tagged carcasses were pitched from the river after the carcass tag was removed. When previously live-tagged

carcasses were recovered, the spaghetti tag number was recorded and the carcass was treated in the same way as other carcasses in the Jolly-Seber program. For purposes of the Petersen estimate, double counting of recoveries was prevented by excluding recoveries of carcass-tagged fish from the "total tagged recovered" term in the Petersen formula given above.

On September 12, 1985, two broomstick carcass weirs were established to measure carcass movement out of the upper and lower river sections. The weirs were located such that they would sample carcasses from the upper river (in B.C. Wright's Pool) and lower river (200 m downstream from the Fisheries Pool) (Fig. 1). Each weir spanned 60-70% of the stream width and was angled upstream. Weirs were cleaned once a day at approximately 1900 hrs. Both weirs were partially washed out on October 15, 1985 and remaining sections were subsequently removed. Carcass weirs were not used in 1984 or 1986. Potentially different washout rates of males and females were tested using a contingency χ^2 test to compare the relative number of males recovered at the weir and in the dead recovery.

The potential bias in the Petersen estimate created by tagging mortality was examined by a contingency χ^2 test to compare the relative number of unspent females among the tagged and untagged fish in the dead pitch. Potentially different washout rates of tagged and untagged carcasses was tested using a contingency χ^2 test to compare the relative number of tagged fish recovered among the tagged and untagged fish recovered at the weirs and in the 1985 dead recovery.

Calculations relating to dead recovery in the Petersen method were as follows:

$$\text{Tag rate} = \frac{\text{Total tagged recovered}}{\text{Total dead recovered}}$$

$$\text{Tag recovery rate} = \frac{\text{Total tagged recovered}}{\text{(Total tagged) - (Tags removed in eggtake)}}$$

$$\text{Punch recovery rate} = \frac{\text{Total punched recovered}}{\text{(Total tagged and punched) + (Total punched)}}$$

CODED WIRE TAGGING AND RECOVERY

No sampling for coded wire tags (CWT) was performed in 1984. Coded wire tagged chinook were released into the Atnarko River in 1975 to 1978 and 1981 to 1985. Chinook from the 1981 brood year were marked with two tag codes (02-21-54 and 02-21-55) representing imprinting and non-imprinting experimental release treatments, respectively. Juveniles from the imprinting treatment were released 0.5 km upstream of Fisheries Pool

(Fig. 1) and those from the non-imprinting treatment were released at the Atnarko Slough. Each year from 1982 to 1985, three or more coded wire tagged groups of chinook juveniles were released into the Atnarko River. Standard methods of coded wire tagging were used (e.g. Armstrong and Argue 1977). Adipose fins of coded wire tagged juveniles were clipped prior to release of the fish to flag the presence of CWTs in returning adults. Binary coded wire tags have been described fully by Jefferts et al. (1963).

All carcasses handled in 1985 and all live fish and carcasses handled in 1986 were examined for adipose fin clips. In 1986, numbers of adipose clips observed on live fish were recorded prior to live-tagging and release or removal for broodstock. Heads from adipose-clipped carcasses obtained in the dead recovery and broodstock collection were delivered to the Snootli Creek Hatchery where coded wire tags were removed and decoded.

Estimation of the total number of CWT returns from each of these brood years and for each tag code is a three step process:

1) determining the appropriate samples and population strata to use for estimating the overall adipose clip rate (using either the samples taken in the broodstock collection and live tagging or the dead recovery, or some combination of the two);

2) determining the proportion of the population examined to produce the observed number of adipose clips. This is then used to calculate the total number of adipose clips estimated to be in the escapement; and

3) allocating the total number of adipose clips estimated to be in the escapement among the tag codes in proportion to those successfully decoded.

This scheme of first estimating the expected numbers of adipose-clipped fish and then allocating these among the successfully decoded CWTs assumes that the lost pin/no pin fish in the sample represent fish that were once tagged but have lost their tags for some reason. It is possible (particularly in the dead pitch program) that some fish identified as hatchery releases by missing adipose fins may be natural fish that have lost their adipose fins through some other means; e.g. carcass decomposition. If decomposition of adipose fins is occurring, then the adipose clip rate in the dead pitch should be higher than that observed in the live tagging program. This was examined by a contingency χ^2 test to compare the adipose clip rate in live tagging with that in the dead recovery for 1986 (males and females pooled). A potentially more important problem in the 1986 study was that heads were collected from adipose clipped fish in the dead pitch only if the sampler was very certain that the adipose fin was missing, rather than sampling all fish that appeared to be missing their adipose fin. In this procedure, the samplers may have missed some clips.

The circumstances and methods of recovering coded wire tagged heads differed slightly between the 1985 and 1986 programs. Thus, the results from the two years are presented separately. Due to the different ages

at maturity of returning males and females, it is important that calculations are carried out separately by sex whenever possible. Due to small sample sizes, the recoveries of jacks have been excluded from the analysis which follows. In both years, there were low total recoveries of adipose clips therefore we do not present a separate estimate for the upper and lower river areas.

In 1985, the escapement of adipose clips was estimated using the Jolly-Seber escapement estimates for each sex and the weighted mean of the adipose clip mark rates in the Snootli Hatchery broodstock collection and the dead recovery samples.

In 1986, the escapement of adipose clips was estimated using the Petersen escapement estimates for each sex (upper and lower rivers pooled) and the weighted mean of the adipose clip mark rates in the live tagging and broodstock collection (samples pooled) and the dead recovery samples.

Given an estimate of the number of adipose clips escaping to the river, the escapement of each tag code was estimated by allocating the total escapement of clips among the individual tag codes observed in the river based on their relative frequency in the sample of decoded tags. This is a valid procedure if the adipose clips and decoded tags are from the same population. Decoded tags included those from the broodstock collection and live tagging, the dead recovery, the Indian Food Fishery, and the sport fishery. Sexes were pooled in the allocation of clips among the tag codes as some CWT recoveries were not recorded by sex. The hatchery contribution to escapement from each of the age groups was estimated by applying the marked to unmarked ratios at release.

Sources of Error in CWT Estimates

Potential sources of error in coded wire tag analyses include inaccurate adipose clip rates (indicated by different mark rates between broodstock collection/live tagging and dead recovery samples), selective removal of adipose clipped fish in the broodstock collection and live tagging programs, patchiness of adipose clipped fish in the river, small samples of marked fish, and nonrandom sampling of coded wire tagged fish for decoding of tags. As potential sources of bias can render calculations of the level of precision of the escapement estimates of adipose-clipped fish and individual tag codes misleading, we did not perform these calculations except to examine the 95% confidence limits of the number of adipose clips observed.

BIOLOGICAL AND PHYSICAL SAMPLING

During live tagging in 1986, biological sampling of fish included sex, presence of adipose clips, and scales for age determination (Table 2). The date, sampling reach, and live tag number were recorded.

In the 1984 Jolly-Seber field program, sex, presence of adipose clips, date, sampling reach, and tag colour of carcass tags applied and recovered were recorded. In 1984, carcasses that could not be retrieved for tagging but could be sexed were counted, and carcasses that could not be sexed were ignored. Systematic scale sampling was not performed.

In 1985 and 1986, biological sampling of fish during Jolly-Seber carcass tagging and recovery included sex, spawning condition, presence of adipose clips, presence of live-tags (1986 only) or carcass tags, and scales for age determination. The date, sampling reach, and tag color or number (applied or recovered) were recorded. For most adipose clipped carcasses, postorbital-hypural length (± 0.5 cm) measurements and scale samples were taken. Efforts were made to obtain postorbital-hypural length (POHL) measurements of fish marked with adipose fin clips; however, fish were tagged and released as quickly as possible to avoid mortality therefore not all fish were measured. Spawning condition was recorded as spent (completely void of eggs or milt), partially spent (some eggs or milt remained), or as unspawned pre-spawned mortality (gonads were intact and all eggs or milt appeared to be retained).

The objective of scale sampling was to obtain the age composition of the population by sex to apply to the escapement and CWT estimates. In 1985 and 1986, scales (10 scales per carcass) were taken from a sub-sample of carcasses examined from all river sections sampled during the studies. Scales were stored on gummed scale cards and later analysed at the Department of Fisheries and Oceans Scale Laboratory in Vancouver. Date, sex, postorbital-hypural length (POHL), sampling reach, and recovery method (stream or carcass weir) were recorded for each fish sampled. Scales in 1986 showed a high degree of resorption and regeneration therefore age determinations were not possible. Chinook scales and lengths from the 1986 Indian food fishery (IFF) downstream of the mouth of the Atnarko River were used to approximate the age composition of 1986 Atnarko chinook. The IFF data were sampled between May 4 and June 18, 1986. To test whether the IFF sampled the same population as the Atnarko River dead recovery, Kolmogorov-Smirnov tests (Sokal and Rohlf 1969) were used to compare the length frequency distributions of the IFF and dead recovery samples.

Bias in the readability of scales with age could occur if older fish tend to have more resorbed or regenerate scales than younger fish. To examine this potential problem, we used Kolmogorov-Smirnov tests to compare the length frequency distributions of fish with ages determined and those without ages determined for 1985 dead recovery and 1986 Indian Food Fishery samples (sexes separate). In addition, we categorized the 1985 scales into "good" or "poor" readability based on regeneration, resorption, and quality of scale preparation, and compared the mean lengths of carcasses.

To determine whether the 1985 and 1986 escapement populations were of the same age and length compositions, Kolmogorov-Smirnov tests were used to compare the age and length frequency distributions of 1985 and 1986 dead recovery samples for sexes separately. The IFF lengths were pooled with the 1986 dead recovery lengths if the length frequency distributions of these samples were not significantly different. In 1986, the IFF age frequency distribution was compared with the 1985 age frequency distribution as ages were not determined from 1986 dead recovery samples.

To determine whether males and females were of the same length and age compositions in 1985 and 1986, Kolmogorov-Smirnov tests were used to compare the age and length frequency distributions of the sexes for each

year separately. In 1986, the IFF age data were used to test whether males and females were of the same age composition.

Carcasses from which scales were taken may not have represented an unbiased sample of the whole population due to the potential for differential washout rates by age or the differential catch by age of gillnets. Testing for this potential bias was not possible using data from this study.

Stream flow data for the Atnarko River near the mouth for each year of the study were obtained from the Water Survey of Canada (Station 08FB006).

RESULTS

TAGGING

Petersen Method - Live Tagging

Tagging was conducted in from one to six reaches of the nine tagging reaches per day (Appendix 1). During the 1986 Petersen tagging study, a total of 1,442 live chinook were tagged with numbered spaghetti tags, which was over 10% of the estimated population (Table 4). In both the upper and lower rivers, more females (n = 822) than males (n = 617) were captured and tagged, and very few jacks were captured (n = 3). A total of 115 fish were released tagged and not opercular punched, and four fish were released punched but not tagged. A total of 1,327 fish released were both punched and tagged. Two males and 27 tagged females were removed for broodstock eggtake.

Tag loss in 1986 was 54.7% and 50.7% for males and females, respectively (Table 4). Tag loss was independent of sex (χ^2=0.40, df=1, p>.05).

Live-tagged females had a significantly greater rate of mortality than untagged females as indicated by the difference in the relative number of spent females in the dead recovery samples of tagged and untagged females (tagged females = 82.9% spent (n=2,467), untagged = 98.3% (n=303); contingency χ^2=7.58, df=1, p<.01).

Jolly-Seber Method - Carcass Tagging

Carcass sampling was conducted during 12 sampling periods in 1984, nine periods in 1985, and five periods in 1986 (Appendices 2 and 3). Carcass tagging was conducted in each of these periods except the last period in each year, during which sampling was conducted for recoveries only. A total of 3,581 carcasses were tagged in 1984, 7,536 were tagged in 1985, and 2,825 were tagged in 1986 (Tables 5 to 7).

RECOVERY

Recovery effort for carcass tags and live tags from carcasses is presented in Appendices 2, 4 and 5. These data were not available for 1984. A total of 7,728 carcasses were examined for tags in 1984, 12,477 carcasses in 1985, and 4,918 carcasses in 1986 (Tables 5 to 7).

Table 4. Summary of live-tagging and dead recovery of chinook salmon in the Atnarko River, 1986.

Item	Sex			Total
	Males	Females	Jacks	
Tagging Program				
Tagged and punched[a]	561	763	3	1,327
Tagged but not punched	56	59	0	115
Punched but not tagged	2	2	0	4
Tags removed in eggtake	2	27	0	29
Dead Recovery Program				
Recovered	1,675	3,117	126	4,918
Punched recovered	88	186	0	274
Tagged recovered	72	180	0	252
Other[b]				
Tag rate	4.3%	5.8%	0.0%	5.1%
Tag recovery rate	11.7%	22.6%	0.0%	17.8%
Punch recovery rate	15.6%	24.3%	0.0%	20.6%
Tag loss	54.7%	50.7%	-	52.0%

[a] Punched means marked with a punched hole in operculum.
[b] See methods section (Tagging and Recovery) for method of calculation.

Table 5. Summary of chinook salmon carcass tagging and recovery on the Atnarko River, 1984. Recovered tagged carcasses and sampled carcasses that were not tagged were returned to the system.

Sampling period and location[a]	Number tagged and released	Number examined	Tag recoveries by release period										
			1	2	3	4	5	6	7	8	9	10	11
Upper River Males													
1	0	1											
2	0	0	0										
3	2	2	0	0									
4	5	6	0	0	1								
5	23	31	0	0	0	7							
6	29	34	0	0	0	0	4						
7	79	117	0	0	0	2	9	20					
8	96	176	0	0	1	1	12	20	44				
9	125	231	0	0	0	2	6	13	30	55			
10	113	267	0	0	0	3	6	5	23	35	82		
11	113	323	0	0	0	2	6	5	14	37	62	84	
12	0	11	0	0	0	0	0	0	0	2	2	4	2
Total	585	1,199	0	0	2	17	43	63	111	129	146	88	2
Lower River Males													
1	2	2											
2	6	7	1										
3	8	12	2	1									
4	33	39	0	2	3								
5	0	0	0	0	0	0							
6	90	105	0	0	0	3	0						
7	125	185	0	0	0	2	0	49					
8	87	185	0	0	1	6	0	32	58				
9	140	291	0	1	0	7	0	30	46	50			
10	57	206	0	0	1	3	0	16	36	33	60		
11	0	176	0	0	0	1	0	7	19	24	52	29	
Total	548	1,208	3	4	5	22	0	134	159	107	112	29	
Upper River Females													
1	0	1											
2	2	2	0										
3	18	19	0	1									
4	25	30	1	1	3								
5	86	109	1	1	3	16							
6	62	89	0	0	3	2	22						
7	165	230	0	0	1	6	23	28					
8	168	305	0	0	1	3	15	21	92				
9	204	446	0	0	0	4	17	25	79	117			
10	209	560	0	0	2	2	12	21	63	107	144		
11	163	603	0	0	1	1	9	16	63	94	110	146	
12	0	22	0	0	0	0	0	0	1	4	6	3	6
Total	1,102	2,416	2	3	14	34	98	111	298	322	260	149	6

continued

Table 5. Continued

Sampling period and location[a]	Number tagged and released	Number examined	Tag recoveries by release period										
			1	2	3	4	5	6	7	8	9	10	11
Lower River Females													
1	13	13											
2	11	17	6										
3	34	43	1	6									
4	70	90	2	3	15								
5	0	0	0	0	0	0							
6	125	148	0	0	3	14	0						
7	149	254	0	0	5	16	0	71					
8	167	370	0	0	5	24	0	61	110				
9	231	494	0	0	4	14	0	62	87	86			
10	111	441	0	0	3	14	0	37	66	75	145		
11	0	345	0	0	2	7	1	27	42	57	93	63	
Total	911	2,215	9	9	37	89	1	258	305	218	238	63	
Upper River Jacks													
1	0	0											
2	1	1	0										
3	0	0	0	0									
4	2	2	0	0	0								
5	14	15	0	0	0	0							
6	10	11	0	0	0	0	1						
7	30	36	0	0	0	0	3	2					
8	28	43	0	0	0	1	3	0	11				
9	67	102	0	0	1	0	0	3	12	19			
10	80	131	0	0	0	0	1	0	4	13	33		
11	40	94	0	0	0	0	0	0	7	9	19	19	
12	0	2	0	0	0	0	0	0	0	0	0	0	2
Total	272	437	0	0	1	1	8	5	34	41	52	19	2
Lower River Jacks													
1	0	0											
2	2	2	0										
3	4	4	0	0									
4	8	10	0	0	1								
5	0	0	0	0	0	0							
6	17	17	0	0	0	0	0						
7	26	29	0	0	0	0	0	3					
8	24	33	0	0	0	0	0	4	5				
9	56	70	0	0	0	0	0	2	5	5			
10	26	57	0	0	0	0	0	1	6	7	17		
11	0	31	0	0	0	0	0	1	3	4	8	5	
Total	163	253	0	0	1	0	0	11	19	16	25	5	

[a] Sampling period 1 = Sept. 4 - 5; 2 = Sept. 7 - 8; 3 = Sept. 10 - 11; 4 = Sept. 13 - 14; 5 = Sept. 16 - 17; 6 = Sept. 19 - 20; 7 = Sept. 22 - 23; 8 = Sept. 25 - 26; 9 = Sept. 28 - 29; 10 = Oct. 1 - 2; 11 = Oct. 4 - 5; 12 = Oct. 21.

Table 6. Summary of chinook salmon carcass tagging and recovery on the Atnarko River, 1985. Recovered tagged carcasses and sampled carcasses that were not tagged were not returned to the system.

Sampling period and location[a]	Number tagged and released	Number examined	Tag recoveries by release period							
			1	2	3	4	5	6	7	8
Upper River Males										
1	16	16								
2	34	40	5							
3	89	106	0	17						
4	330	390	1	2	57					
5	328	484	0	1	16	139				
6	315	536	0	0	6	38	177			
7	248	415	0	0	0	7	17	143		
8	151	278	0	0	0	2	11	27	87	
9	0	115	0	0	0	0	1	4	7	44
Total	1,511	2,380	6	20	79	186	206	174	94	44
Lower River Males										
1	21	21								
2	68	73	5							
3	258	288	2	28						
4	375	524	0	7	142					
5	408	632	0	6	11	207				
6	312	585	0	3	4	38	228			
7	254	439	0	1	5	6	13	160		
8	0	173	0	0	0	4	8	19	61	
Total	1,696	2,735	7	45	162	255	249	179	61	
Upper River Females										
1	22	22								
2	75	86	7							
3	131	157	4	22						
4	259	365	1	13	92					
5	381	607	0	4	12	210				
6	473	753	0	0	5	35	240			
7	278	672	0	0	1	5	26	262		
8	261	473	0	0	0	5	19	54	134	
9	0	174	0	0	0	1	1	2	10	83
Total	1,880	3,309	11	39	110	256	286	318	144	83

continued

Table 6. Continued

Sampling period and location[a]	Number tagged and released	Number examined	Tag recoveries by release period							
			1	2	3	4	5	6	7	8
Lower River Females										
1	37	37								
2	76	94	18							
3	227	266	1	38						
4	440	619	3	7	169					
5	420	729	1	6	28	274				
6	390	682	2	1	11	30	248			
7	254	549	0	2	4	13	17	259		
8	0	245	0	0	0	3	0	17	100	
Total	1,844	3,221	25	54	212	320	265	276	100	
Upper River Jacks										
1	0	0								
2	3	3	0							
3	3	3	0	0						
4	18	19	0	0	1					
5	61	71	0	1	1	8				
6	125	165	0	0	0	3	37			
7	38	51	0	0	0	0	1	12		
8	0	21	0	0	0	0	0	3	1	
Total	248	333	0	1	2	11	38	15	1	
Lower River Jacks										
1	2	2								
2	6	6	0							
3	32	34	0	2						
4	48	58	0	3	7					
5	97	139	0	2	3	37				
6	142	202	0	1	2	3	54			
7	30	53	0	0	0	1	1	21		
8	0	5	0	0	0	0	0	0	3	
Total	357	499	0	8	12	41	55	21	3	

[a] Sampling period 1 = Sept.12-15; 2 = Sept.16-19; 3 = Sept.20-23; 4 = Sept.24-27; 5 = Sept.28-Oct.1; 6 = Oct.2-5; 7 = Oct.6-9; 8 = Oct.10-13; 9 = Oct.14-17.

Table 7. Summary of chinook salmon carcass tagging and recovery on the Atnarko River, 1986. Recovered tagged carcasses and sampled carcasses that were not tagged were not returned to the system.

Sampling period and location[a]	Number tagged and released	Number examined	Tag recoveries by release period			
			1	2	3	4
Upper River Males						
1	14	14				
2	92	99	7[b]			
3	187	237	1	49		
4	152	291	0	10	129	
5	0	94	0	1	3	136
Total	445	735	8	60	132	136
Lower River Males						
1	52	52				
2	170	201	31[c]			
3	315	398	4	79		
4	47	218	0	8	163	
5	0	71	0	0	8	84
Total	584	940	35	87	171	84
Upper River Females						
1	68	68				
2	274	308	34[d]			
3	374	556	6	176		
4	94	446	3	10	339[e]	
5	0	235	1	3	17	227
Total	810	1,613	44	189	356	227
Lower River Females						
1	117	117				
2	322	371	49[c]			
3	410	573	7	156		
4	51	347	0	21[c]	275[c]	
5	0	96	1	5[c]	23	145
Total	900	1,504	57	182	298	145

continued

Table 7. Continued

Sampling period and location[a]	Number tagged and released	Number examined	Tag recoveries by release period			
			1	2	3	4
Upper River Jacks						
1	0	0				
2	8	8	0			
3	19	21	0	2		
4	10	15	0	0	5[b]	
5	0	8	0	0	0	3
Total	37	52	0	2	5	3
Lower River Jacks						
1	2	2				
2	5	5	0			
3	42	45	0	3		
4	0	13	0	0	14	
5	0	9	0	0	1	5
Total	49	74	0	3	15	5

[a] Sampling period 1 = Sept. 16-19; 2 = Sept. 21-25; 3 = Sept. 28-Oct. 2; 4 = Oct. 5-9.
[b] Includes one stray from the lower river.
[c] Includes one stray from the upper river.
[d] Includes two strays from the lower river.
[e] Includes five strays from the lower river; two strays from the lower river recorded as tagged and recovered in sampling period 4 were omitted from the Jolly-Seber calculations.

For five sampling periods of Jolly-Seber recovery, a greater number of tags were recovered than were released (i.e. 1984 lower river jacks, period 4; 1986 lower river males, period 4; 1986 upper river females, period 4; 1986 lower river females, period 4; 1986 lower river jacks, period 4). In 1984, recovered carcasses that were tagged were replaced, therefore, at least for the lower river jacks, some carcasses were examined more than once. In 1985 and 1985, recovered carcasses that were tagged were not replaced, therefore the high number of tag recoveries in these cases reflect problems in the data.

A total of 10 tagged and 130 untagged carcasses were recovered at the upper and lower river carcass weirs in 1985 (Table 8). There was a significantly higher relative number of males at the carcass weirs than in the dead pitch (Tables 6 and 8; $\chi^2=5.54$, df=1, $p<.05$). In addition, there was a significantly higher relative number of tagged fish at the carcass weirs than in the dead pitch ($\chi^2=74.22$, df=1, $p<.001$).

Most recoveries of live tags were in the same river area (i.e. upper or lower river areas) where they were originally tagged and released (Appendices 6 and 7). However, there was some straying of tagged fish between the upper and lower river areas (see population estimate results section).

In each dead recovery program from 1984 to 1986, more females were recovered than males, and fewer jacks were pitched than either males or females (Tables 4 to 7). For example, in 1984, 2,407 males, 4,631 females, and 690 jacks were recovered (Table 5).

Carcass tag recovery was 35.86% in 1985 (4,474 tags recovered out of 12,477 tags applied) and 45.63% in 1986 (2,244 tags out of 4,918 tags applied). In 1984, there was a high degree of multiple recoveries of tagged carcasses due to the replacement of tagged carcasses in the Jolly-Seber method (3,940 tag recoveries from 3,581 tags applied). In 1986, the recovery rate of Petersen tags was 17.8% and opercular punches was 20.6% (Table 4).

POPULATION ESTIMATES

Petersen Method

In 1986, the Petersen estimates of the chinook escapement to the Atnarko River were 7,429 males and 6,589 females for a total estimated escapement of 14,018 adults (Table 9). A summary of these estimates and their confidence limits is presented in Table 10.

It was observed that the tagged to untagged ratio in the dead pitch declined toward the end of the survey. This may have been caused by fish moving into the system after tagging ended. If dead recovery effort was assumed to be constant throughout the dead recovery program (effort was not recorded in terms of time spent searching for carcasses), the Petersen estimate would be an overestimate the of population due to an inflated dead recovery of untagged carcasses.

Table 8. Carcass recoveries from the carcass weirs in the Jolly-Seber study on the Atnarko River, 1985.

	Upper weir		Lower weir	
Sex	Tagged	Untagged	Tagged	Untagged
Males	2	52	0	20
Females	3	41	0	10
Jacks	0	6	0	1
Total	5	99	0	31

Table 9. Petersen tag-recapture estimates of chinook salmon escapement to the upper and lower Atnarko River, 1986.

Location[a] and item	Male	Female	Jack	Total
Upper River				
Tagged	302	403	1	706
Tags removed in eggtake	2	18	0	20
Tagged, not punched	49	45	0	94
Dead recovery	735	1,613	52	2,400
Tag recovery	39	103	0	142
Tagged strays recovered from lower river	2	11	0	13
Tagged available corrected for tags removed in eggtake and straying[b]	97	552	0	649
Tag recovery corrected for tag loss[b]	86	209	0	295
Petersen estimate, sexes separate[b]	829	4,250	-[c]	5,079
Lower River				
Tagged	315	419	2	736
Tags removed in eggtake	0	9	0	9
Tagged, not punched	7	14	0	21
Dead recovery	940	1,504	74	2,518
Tag recovery	33	77	0	110
Tagged strays recovered from upper river	7	2	0	9
Tagged available corrected for tags removed in eggtake and straying[b]	518	243	0	761
Tag recovery corrected for tag loss[b]	73	156	0	229
Petersen estimate, sexes separate[b]	6,600	2,339	-[c]	8,939

[a] See Table 1 for the location of the upper and lower river areas.

[b] See methods section for method of calculation.

[c] No recaptures of tagged or punched jacks; insufficient data to estimate escapement.

Table 10. Summary of Petersen tag-recapture estimates of chinook salmon escapement to the Atnarko River, 1986.

Strata[a]	Escapement estimate	95% CL[b]	
		Lower	Upper
Upper River Males	829	0	1,879
Lower River Males	6,600	0	18,704
Upper River Females	4,250	0	11,131
Lower River Females	2,339	0	5,626
Total	14,018	0	28,362

[a]See Table 1 for the boundaries between upper and lower rivers.

[b]See methods section for method of calculation of confidence limits.

Jolly-Seber Method

In 1984, the Jolly-Seber estimate of the chinook escapement to the Atnarko River was 1,764 males, 4,244 females, and 754 jacks for a total escapement estimate of 6,762 fish (Appendices 8 to 14). In 1985, escapement estimates were 4,707 males and 5,027 females for a total of 9,734 adults (Appendices 15 to 20). In 1986, escapement estimates were 1,287 males and 2,243 females for a total of 3,530 adults (Appendices 21 to 24). Summaries of these estimates and their confidence limits are presented in Tables 11 to 13.

There were a greater number of carcasses in the upper than the lower river in 1984 (60.4% of the escapement), in 1985 approximately half of the carcass population was in the upper river (49.4%), and in 1986 less than half of the carcasses were in the upper river (42.5%).

AGE, LENGTH AND SEX COMPOSITION

In 1985, scales from a total of 548 fish were examined for age. Of these, ages were determined for only 166 males and 146 females as many scales were unreadable due to a high degree of resorption. Of these, freshwater age was not determined for one female. There were an additional 109 males and 91 females for which age was not determined, as well as 36 fish of unknown sex. In 1986, scales from the Indian Food Fishery were used in place of the dead recovery scale samples which were too resorbed for age determinations. Scales from a total of 440 IFF samples were examined for age, of which ages and lengths were determined for 186 males and 211 females. There were an additional 24 males and 18 females for which ages were not determined.

Age, Length and Sex Composition

In 1985, ages of returning Atnarko chinook ranged from 2_1 to 6_2 (Table 14) and in 1986 from 3_1 to 6_2 (Table 15). In 1985, the mean ages of sampled females (mean=4.6 years) was slightly, but not significantly, greater than that of sampled males (mean=4.2 years; t-test, $p>.2$; n=166 (males), 146 (females)). In 1986, the mean age of both males (n=187) and females (n=211) was 4.8 years.

Males in the 1985 dead recovery were significantly younger (mean=4.3 years, n=166) than 1986 males in the IFF (mean=4.9 years, n=187) (t-test, $p<.001$), but there was no significant difference in the age of 1985 females in the dead recovery (mean=4.6 years, n=146) and 1986 females in the IFF (mean=4.7 years, n=211) (t-test, $p>.05$). The test for females may not be a valid comparison because samples of 1986 females from the IFF and dead recovery were each not unbiased samples of the escapement population (see below).

In 1985, the predominant age class of males was 4_2 and of females was 5_2 (Table 14). In 1986, the predominant age classes of both males and females was 5_1, and secondarily 5_2 (Table 15). Most chinook (87%) were sub-2s in the 1985 sample, while only 43.5% were sub-2s in 1986. For both years, fish in the younger age classes (ages 4 or less) showed

Table 11. Jolly-Seber tag-recapture estimates of chinook salmon escapement to the Atnarko River, 1984.

Strata[a]	Escapement estimate	95% CL[b]	
		Lower	Upper
Upper River Males	731	656	820
Lower River Males	1,033	827	1,278
Upper River Females	2,923	2,721	4,075
Lower River Females	1,321	1,200	1,476
Upper River Jacks	430	377	512
Lower River Jacks	324	138	415
Total	6,762	6,077	7,571

[a] See Table 1 for the boundaries between upper and lower rivers.

[b] See Webb (1988) for method of calculation by Monte Carlo simulation.

Table 12. Jolly-Seber tag-recapture estimates of chinook salmon escapement to the Atnarko River, 1985.

Strata[a]	Escapement estimate	95% CL[b]	
		Lower	Upper
Upper River Males	2,200	2,311	2,403
Lower River Males	2,507	2,285	2,860
Upper River Females	2,605	2,482	2,762
Lower River Females	2,422	2,348	2,727
Total	9,734	9,359	10,109

[a] See Table 1 for the boundaries between the upper and lower rivers.

[b] See Webb (1988) for method of calculation by Monte Carlo simulation.

Table 13. Jolly-Seber tag-recapture estimates of chinook escapement to the Atnarko River, 1986.

Strata[a]	Escapement estimate	95% CL[b]	
		Lower	Upper
Upper River Males	509	424	594
Lower River Males	778	579	951
Upper River Females	992	916	1,048
Lower River Females	1,251	1,073	1,405
Total	3,530	3,258	3,802

[a] See Table 1 for the boundaries between the upper and lower rivers.

[b] See Webb 1988 for method of calculation by Monte Carlo simulation.

Table 14. Age and length composition of Atnarko River chinook salmon from the dead recovery, 1985.

Age	Number of age determinations	Percent	Postorbital-hypural length (mm)			
			Mean	Standard deviation	95% CL	
					Lower	Upper
Males						
2_1	3	1.8	285.0	57.6	219.8	350.2
3_1	5	3.0	609.0	36.9	576.7	641.3
3_2	14	8.4	508.2	90.8	460.6	555.8
4_1	10	6.0	777.0	60.2	739.7	814.3
4_2	76	45.9	688.4	69.4	672.8	704.0
5_1	2	1.2	830.0	30.0	788.4	871.6
5_2	46	27.7	794.2	51.2	779.4	809.0
5_3	2	1.2	765.0	35.0	716.5	813.5
6_2	8	4.8	848.1	70.3	799.4	896.8
Total=	166	100.0	Mean=685.0[a]	143.0[a]		
Females						
3_1	1	0.7	570.0	-	-	-
3_2	1	0.7	540.0	-	-	-
4_1	15	10.3	771.3	64.1	738.9	803.7
4_2	44	30.3	772.8	42.2	710.3	835.3
5_1	1	0.7	770.8	-	-	-
5_2	74	51.0	770.8	59.0	757.4	784.2
6_2	9	6.3	754.0	68.1	709.5	798.5
Total=	145	100.0	Mean=746.0	67.1		

[a] Includes carcasses that could not be accurately aged.

Table 15. Age and length composition of Atnarko River chinook salmon from the Indian Food Fishery, 1986.

Age	Number of age determinations	Percent	Postorbital-hypural length (mm)			
			Mean	Standard deviation	95% CL	
					Lower	Upper
Males						
3_1	2	1.1	483.5	37.5	431.5	535.3
4_1	24	12.9	688.4	53.0	667.4	709.4
5_1	79	42.4	803.0	48.0	785.6	820.4
5_2	60	32.3	723.8	49.6	711.2	736.4
6_2	21	11.3	806.7	61.2	780.5	832.9
Total=	186	100.0	Mean=757.0	82.6		
Females						
3_1	10	4.7	517.8	57.5	482.2	553.4
3_2	2	0.9	493.0	87.0	457.4	528.6
4_1	37	17.4	678.8	58.0	660.1	697.5
4_2	9	4.2	558.6	28.7	539.8	577.4
5_1	73	34.3	780.0	49.4	768.7	791.3
5_2	68	31.9	705.0	56.1	691.7	718.3
6_2	14	6.6	801.0	53.0	773.2	828.8
Total=	213	100.0	Mean=715.2	91.5		

a slightly greater tendency to be sub-1 (43%) than fish in the older age classes (ages 5 and 6) (33%).

The population in each age class is shown in Tables 16 and 17 for 1985 and 1986, respectively.

In 1985, the length frequency distribution of females was significantly different from that of males (Kolmogorov-Smirnov test, Dmax=0.308705, 20 groups, n=275 (males), n=236 (females), p<.05), and the mean length of females (746.0 mm) was greater than that of males (685.1 mm; Table 14). In 1986, the length frequency distributions were significantly different (Kolmogorov-Smirnov test using dead recovery lengths, Dmax=0.437615, 18 groups, n=307 (males), 204 (females), p<.01), but the mean length of males (757.0 mm) was greater than that of females (715.2 mm; Table 15).

Males in the 1985 dead recovery were of the same length frequency distribution as 1986 males in the IFF and dead recovery samples pooled (Kolmogorov-Smirnov test, Dmax=0.16412, 20 groups, n=275 (in 1985), 518 (in 1986), p>.05), and 1985 and 1986 females in the dead recovery samples were of the same length frequency distribution (Kolmogorov-Smirnov test, Dmax=0.231363, 12 groups, n=236 (in 1985), 201 (in 1986), p>.05).

The ratios of males to females from the Jolly-Seber population estimates were 30.1%:69.9% in 1984, 48.4%:51.6% in 1985, and 36.5%:63.5% in 1986 (Tables 11 to 13). The sex ratio from the 1986 Petersen estimate was 53.0% males to 47.0% females (Table 10).

Biases in Age and Length Analyses

Kolmogorov-Smirnov tests indicated that there were no significant differences between the length frequency distributions of fish with ages determined and fish without ages determined due to unreadable scales (1985 males: Dmax=0.209088, 20 groups, n=165 (ages), 110 (without ages), p>.05; 1985 females: Dmax= 0.136528, 12 groups, n=146 (ages), 90 (without ages), p>.05; 1986 males: Dmax=0.099797, 20 groups, n=187 (ages), 24 (without ages), p>.05; 1986 females: Dmax=0.135289, 15 groups, n=211 (ages), 18 (without ages), p>.05; Table 18). These results indicate that there was no bias in readability of scales with age.

As age determinations of 1986 dead recovery samples were not possible, 1986 IFF age and length data were used in the comparisons above. Kolmogorov-Smirnov tests indicated that there was no significant difference between the length frequency distributions of 1986 IFF and dead recovery samples of males (Dmax=0.239498, 20 groups, n=211 (IFF), 307 (dead recovery), p>.05) but indicated a highly significant difference between those of 1986 females (Dmax=0.439656, 14 groups, n=229 (IFF), 201 (dead recovery), p<.01).

CODED WIRE TAGGING AND RECOVERY

Hatchery-reared juvenile chinook from the 1981, 1982, 1983, and 1985 brood years that were released into the Atnarko River with coded wire tags were recovered in the chinook escapement enumeration programs

Table 16. Jolly-Seber estimates allocated by age composition, 1985.

Age	Males		Females	
	Number[a]	Percent[b]	Number[a]	Percent[b]
2_1	85	1.8	0	0.0
3_1	141	3.0	35	0.7
3_2	395	8.4	35	0.7
4_1	282	6.0	518	10.3
4_2	2,161	45.9	1,523	30.3
5_1	56	1.2	35	0.7
5_2	1,304	27.7	2,564	51.0
5_3	56	1.2	0	0.0
6_2	226	4.8	317	6.3
Total	4,707	100.0	5,027	100.0

[a] Total escapement to upper and lower rivers from Table 12.

[b] From Table 14.

Table 17. Petersen estimates allocated by age composition, 1986.

Age	Males		Females	
	Number[a]	Percent[b]	Number[a]	Percent[b]
3_1	82	1.1	310	4.7
3_2	0	0.0	59	0.9
4_1	958	12.9	1,146	17.4
4_2	0	0.0	277	4.2
5_1	3,150	42.4	2,260	34.3
5_2	2,400	32.3	2,102	31.9
6_2	839	11.3	435	6.6
Total	7,429	100.0	6,589	100.0

[a] Total escapement to upper and lower rivers from Table 10.

[b] From Table 15.

Table 18. Mean length and scale condition of Atnarko River chinook salmon, 1985. (Scales were sampled during the Jolly-Seber carcass recovery.)

Scale condition	Number	Postorbital-hypural length (mm)			
		Mean	Standard deviation	95% CL	
				Lower	Upper
1985[a]					
Readable	325[b]	730.9	100.4	534.0	927.7
Unreadable	220	678.1	142.5	398.8	957.4
1986[c]					
Readable	398	734.6	90.0	558.2	911.0
Unreadable	42	730.2	75.0	583.1	877.3

[a] This analysis includes 275 males, 237 females, and 36 fish of unknown sex.

[b] There were 398 fish with readable scales. Of these, 3 fish were not measured for length. Freshwater age was not determined for 15 fish.

[c] This analysis includes 211 males and 229 females.

in 1985 and 1986. Earlier releases in 1975 to 1978 were not recovered in this study.

The adipose clip rates in the 1985 broodstock collection and 1986 live tagging were significantly greater than those in the dead recoveries of the respective years (1985: contingency χ^2 =55.96, df=1, p<.001; 1986: contingency χ^2=36.09, df=1, p<.001; Tables 19 and 24).

For the purposes of 1985 coded wire tag analyses, adipose clip rates from the hatchery broodstock and dead recovery were pooled. There were no age or length data from the former samples to compare with the dead recovery samples to test whether they were unbiased samples of the escapement populations. Similarly, in 1986 analyses, adipose clip rates from the hatchery broodstock collection and live tagging programs were pooled with dead recovery data to determine a composite mark rate.

The results of coded wire tag returns are presented separately for 1985 and 1986. The results from each year are summarized in five tables which contain the following items:

1) the raw data and mark rates for the calculations (Tables 19 and 24);

2) the total estimated adipose clips by two methods (i.e. in the population at the time of hatchery broodstock collection (1985) or live tagging (1986) and dead recovery) (Tables 20 and 25);

3) data for calculating the weighted average of the total estimated adipose clips from the two methods (Tables 21 and 26);

4) the weighted average of the total number of adipose clips partitioned between tag codes, and the hatchery contribution to the escapement for each tag code (Tables 22 and 27); and

5) the estimated hatchery contribution to the escapement by age class (Tables 23 and 28).

1985 Recoveries

Sample sizes and numbers of adipose clips observed in the 1985 program are shown in Table 19. The adipose clip rate was significantly higher in the hatchery broodstock than the dead recovery sample, as noted above (i.e. 2.65% in the broodstock and 0.42% in the dead recovery; contingency χ^2 =55.96, df=1, p<.001).

The estimate of total adipose clips in the broodstock sample was 258 fish and in the dead recovery was 41 fish (Table 20). The total escapement of adipose clips weighted by sample size in these two samples was 62 fish (Table 21).

The allocation of the total escapement of adipose clips to tag codes in brood years 1981 and 1982 is shown in Table 22. The estimated hatchery contribution to the 1985 escapement, based on the marked to

Table 19. Sample sizes and observed adipose clip rates for the Snootli Hatchery broodstock collection and dead recovery samples of chinook salmon in the Atnarko River, 1985.

Sex	Sample size[a]		Number adipose clips observed		Mark rate (%)	
	Hatchery broodstock A	Dead recovery[b] B	Hatchery broodstock C	Dead recovery D	Hatchery broodstock E=C/A	Dead recovery F=D/B
Males		3,348	9	17		0.51
Females		4,031	12	14		0.35
Jacks		624	0	1		0.16
Total excluding jacks	792	7,379	21	31	2.65	0.42

[a] Number of fish examined for tags from Table 6 (total number examined less the total number of recoveries).

[b] Data from R. Hilland, pers. comm., 1988; no breakdown by sex in 1985.

Table 20. Estimates of the total escapement of adipose-clipped chinook salmon to the Atnarko River by two methods, 1985.

Sex	Sample size[a]		Adipose clips observed[a]		Jolly-Seber estimate of population size[d]	Percentage of population sampled		Total estimated adipose clips	
	HB[b]	DR[c]	HB	DR		HB	DR	HB	DR
	A		B		C	D=(A/C)x100		E=(B/A)xC	
Male		3,348		17	4,707		71.1		24
Female		4,031		14	5,027		80.2		17
Total	792	7,379	21	31	9,734	8.14	75.8	258	41

[a] From Table 19.

[b] HB = Hatchery broodstock.

[c] DR = Dead recovery.

[d] From Table 12.

Table 21. Weighted average estimate of the total escapement of chinook salmon adipose clips to the Atnarko River, 1985.

Sex	Total estimated adipose clips[a]		
	Using broodstock sample A	Using dead recovery sample B	Average weighted by sample size C[b]
Males	-	24	-
Females	-	17	-
Total	258	41	62
Total sample size	792	7,379	

[a] From Table 20.

[b] $$C = \frac{(792 \times A) + (7{,}379 \times B)}{792 + 7{,}379}$$

Table 22. Estimates of the total escapement of coded wire tagged chinook salmon to the Atnarko River by tag code, 1985.

Brood year	Tag code	Observed adipose clips[a] A	Estimated adipose clips[b] B	Numbers released[c] Marked C	Numbers released[c] Unmarked D	Estimated hatchery contribution[d] E
1981	022154	43	49	34,703	963	50
	022155	10	11	32,041	6,889	13
1982	022139	1	1	24,517[e]	0	1
Total		54	62			64
	no pin/ lost pin	24				
Total		78				

[a] The observed numbers include recoveries from the Snootli Hatchery broodstock collection (n=21), the dead recovery (n=31), the Indian Food Fishery (n=24), and the sport fishery (n=1).

[b] Estimated adipose clips in the Atnarko River (Indian Food Fishery and sport fishery recoveries were downstream of the mouth);

$$B = \text{Total estimated adipose clips (Table 21)} \times \frac{A}{53 \text{ decoded tags}}$$

[c] Johnson and Longwill (1988).

[d] $$E = B \frac{(C + D)}{C}$$

[e] 2,142 fish were adipose clipped only.

unmarked ratios at release of coded wire tags, was 64 fish (Table 22). The estimated hatchery contribution to the 1985 escapement by age class is shown in Table 23. The total contribution was estimated to be 0.66% of the escapement (Table 23).

1986 Recoveries

Sample sizes and numbers of adipose clips observed in the 1986 program are summarized in Table 24. Most of the adipose-clipped fish were found in the lower river downstream of Young Creek. The adipose clip rate observed in the dead recovery (0.4%) was significantly lower than that in the live tagging and eggtake (2.1%), as stated above Table 24; contingency χ^2=36.09, df=1, p<.001).

The estimate of total adipose clips in the live tagging sample was 288 fish and in the dead recovery was 64 fish (Table 25). The total escapement of adipose clips weighted by sample size in these two samples was 116 fish (Table 26).

The allocation of the total escapement of adipose clips to tag codes recovered in 1986 (brood years 1981 to 1985) is shown in Table 27. The estimated hatchery contribution to the 1986 escapement, based on the marked to unmarked ratios at release of coded wire tags, was 188 fish (Table 27). The estimated hatchery contribution to the 1986 escapement by age class is summarized in Table 28. The total contribution was estimated to be 1.34% of the escapement (Table 28).

In 1986, there was spatial heterogeneity in the distribution of CWTs which may be partially due to effects of the 1981 imprinting at release experiment. Based on the locations of recovery of coded wire tags from these two releases it is clear that marked fish from the "imprinted" treatment were found more frequently in the area of the river near their release location, than were fish from the "non-imprinted" treatment. This was a significant result for CWTs recovered from carcasses (data pooled for both years and reaches 2-4, χ^2=5.63, df=1, p<0.05), and tended in that direction for CWTs recovered in the egg take, although sample sizes were too small to test the result statistically.

In both 1985 and 1986, the number of adipose clips enumerated for each sex ranged from 9 to 17 in the samples used to estimate the numbers of adipose clips in the populations. Based (conservatively) on the assumption of a Poisson distribution, the 95% confidence limits of these numbers range from ± 40% to ± 56% (Table 29). These estimates of precision are necessarily conservative as the expansion factors used to estimate the total number of adipose clips in the escapement are also estimated with error (e.g. the population estimate).

DISCUSSION AND CONCLUSIONS

POPULATION ESTIMATION

The Petersen escapement estimate of chinook salmon to the Atnarko River in 1986 was 14,018 spawners, and the Jolly-Seber estimates were 6,762 spawners in 1984, 9,734 spawners in 1985, and 3,530 spawners in

Table 23. Estimated hatchery contribution to the 1985 Atnarko chinook escapement.

Age	Estimated escapement[a] A	Hatchery contribution[b] B	% Hatchery contribution C=(B/A) x 100
2	85	0	0.00
3	606	1	0.17
4	4,484	63	1.40
5	4,015	0	0.00
6	543	0	0.00
total	9,734	64	0.66

[a]From Table 16.

[b]From Table 22.

Table 24. Sample sizes and observed adipose clip rates from the tagging and dead recovery samples of chinook salmon in the Atnarko River, 1986.

Sex	Sample size		Number adipose clips observed				Mark rate (%)	
			Live tagging			Dead recovery	Live tagging	Dead recovery
	Live tagging[a]	Dead recovery[b]	Kept head	Tagged and released	Total			
	A	B	C	D	E	F	G=E/A	H=F/B
Males	626	1,695	1	12	13	9	2.1	0.5
Females	834	3,117	0	17	17	12	2.0	0.4
Jacks	3	150	0	0	0	0		
Total excluding jacks	1,460	4,812	1	29	30	21	2.1	0.4

[a] Includes all fish tagged and/or opercular punched, as well as fish taken for broodstock (9 males and 12 females).

[b] Number examined less number recovered (from Table 7) plus number removed from the system for head samples (i.e., with adipose clips, column F).

Table 25. Estimates of the total escapement of adipose-clipped chinook salmon to the Atnarko River by two methods, 1986.

Sex	Sample size		Adipose clips observed		Petersen estimates of population size[c]	Percentage of population sampled		Total estimated adipose clips	
	Live tag[a]	Dead rec[b]	Live tag	Dead rec		Live tag	Dead rec	Live tag	Dead rec
	A		B		C	D=(A/C)x100		E=(B/A)xC	
Males	626	1,695	13	9	7,429	8.4	22.8	154	39
Females	834	3,117	17	12	6,589	12.7	47.3	134	25
Total	1,460	4,812	30	21	14,018	10.4	34.3	288	64

[a]Live tagging sample.
[b]Dead recovery sample.
[c]From Table 10.

Table 26. Weighted average estimate of the total escapement of chinook salmon adipose clips to the Atnarko River, 1986.

Sex	Total estimated adipose clips[a]		Average weighted by sample size
	Using live tagging sample A	Using dead recovery sample B	C[b]
Males	154	39	66
Females	134	25	50
Total	288	64	116
Total sample size	1,460	4,812	

[a] From Table 25.

[b] $C = \frac{(1{,}460 \times A) + (4{,}812 \times B)}{1{,}460 + 4{,}812}$

Table 27. Estimates of the total escapement of coded wire tagged chinook salmon to the Atnarko River by tag code, 1986.

Brood year	Tag code	Observed adipose clips[b] A	Estimated adipose clips[c] B	Number released[a] Marked C	Number released[a] Unmarked D	Estimated hatchery contribution[d] E
1981	022154	24	50	34,703	963	51
	022155	20	41	32,041	6,889	50
1982	022559	4	8	68,741	48,125	14
	022139	0	0	24,517	2,142	0
	022501	1	2	38,738	8,259	2
1983	022739	2	4	36,266	81,130	13
	022740	3	6	36,545	84,432	20
	022741	0	0	53,399	116,923	0
	022755	1	2	23,976	49,967	6
	022756	0	0	23,976	49,967	0
1984	023257	0	0	48,646	226,533	0
	023258	0	0	51,192	151,526	0
	023259	0	0	51,638	192,764	0
	023260	0	0	51,672	83,736	0
	right ventral clip	0	0	6,500	0	0
1985 Upper river	023641	0	0	25,611	500	0
	023643	0	0	26,283	73	0
	023750	0	0	25,869	401,856	0
	023752	0	0	26,187	407,478	0
1985 Lower river	023644	0	0	27,350	61	0
	023742	0	0	25,675	879,187	0
	023751	1	2	26,922	408,694	32
	023753	0	0	24,807	381,448	0
Total		56	116			188
	no pin/ lost pin	19				
Total		75				

[a] Johnson and Longwill (1988).

[b] The observed numbers include recoveries from the Snootli Hatchery broodstock collection (n=19 females), the dead recovery (n=25), the Indian Food Fishery (n=26), and the sport fishery (n=5).

[c] $B = \text{Total estimated adipose clips (Table 26)} \times \frac{A}{56 \text{ decoded tags}}$

[e] $E = B \frac{(C + D)}{C}$

Table 28. Estimated hatchery contribution to the 1986 Atnarko chinook salmon escapement.

Age	Estimated escapement[a] A	Hatchery contribution[b] B	% Hatchery contribution C=(B/A) x 100
1	0	32	0.00
2	0	0	0.00
3	451	39	8.65
4	2,381	16	0.67
5	9,912	101	1.02
6	1,274	0	0.00
Total	14,018	188	1.34[c]

[a] From Table 17.

[b] From Table 27.

[c] Does not include ages 1 and 2.

Table 29. Confidence limits for the observed numbers of adipose-clipped chinook salmon in the Atnarko River, 1985-1986.

Year, group and sex	Observed adipose clips	95% CL[a]	
		Lower	Upper
1985 Hatchery Broodstock			
Males	9	4	17
Females	12	6	21
1985 Dead Recovery			
Males	17	10	27
Females	14	8	24
1986 Live Tagging			
Males	13	7	22
Females	17	10	27
1986 Dead Recovery			
Males	9	4	17
Females	12	6	21

[a] Based on a Poisson frequency distribution (Ricker 1975).

1986 (Table 30). These estimates were calculated within the limitations of the data by summing the separate estimates for each sex in upper and lower river areas. Jacks were included in the 1984 Jolly-Seber only; data were insufficient to estimate the escapement of jacks in 1985 and 1986.

Stratification

Several potentially important sources of bias in Petersen and Jolly-Seber estimates were circumvented by stratifying the populations by sex. Results from this study indicated that there were factors that affected sexes differentially. In the 1986 Petersen estimate, the number of males live tagged was 75% of the number of females, whereas the number of males pitched was only 54% of the number of females pitched. The gillnets used to capture fish for tagging may have selected for males due to the greater tangling rate of males caused by their numerous sharp protrusions, particularly in the head area (Wilson and Andrew 1987). In addition, the washout rate of males was greater than that of females. The proportion of male carcasses washed out of the Atnarko River in 1985 and recovered on the carcass weirs was significantly greater than the proportion of male carcasses dead pitched (χ^2=5.54, df=1, p<.05). As discussed earlier, female salmon normally hold over their redds after spawning and tend to move into shallow quiet water as they weaken. This behaviour makes them more recoverable than males, which make a lesser attempt to hold their position and are washed out of the spawning stream by the current. A higher recoverability of females in spawning ground dead pitches has also been noted for sockeye (Petersen 1954), pinks (Ward 1959), and coho (Eames and Himo 1981 and Eames et al. 1981). Although there was a high degree of tag loss (54.7% and 50.7% for males and females, respectively), loss of live tags was not significantly different between males and females (χ^2=0.40, df=1, p>.05). In any future studies, Petersen and Jolly-Seber estimates conducted on the Atnarko River should be designed to stratify the population by sex, and calculate separate estimates by sex.

Potentially important sources of bias were also circumvented by stratifying the populations by upper and lower river areas. Locations of live and carcass tagging relative to locations of recoveries of tags indicated that there was greater movement of tagged fish within river areas than between areas (Appendices 6 and 7). If the upper and lower river spawners are separate subpopulations, they may only be accurately enumerated without stratification by river area if the number of fish tagged and recovered in the two river areas are both equal proportions of the populations in the respective areas. The movement patterns of live and carcass tagged fish indicate that future Petersen and Jolly-Seber estimates conducted on Atnarko River chinook escapement should be calculated by stratifying the population by river areas.

A potentially important source of bias in Petersen estimates is mortality due to tagging. In this study, there was a highly significant degree of mortality due to tagging as indicated by the greater number of tagged spent females relative to untagged spent females (contingency χ^2=7.58, df=1, p<.01). Another test for this bias could be performed using live tag data at a carcass weir, comparing the live tag ratio at the carcass weir to that in the dead recovery. However, no such data

Table 30. Summary of estimates of chinook escapement to the Atnarko River, 1984 - 1986.

Estimation method	Year		
	1984	1985	1986
Petersen[a]			
Estimate			14,018
Upper 95% limit			28,362
Lower 95% limit			0
Jolly-Seber[b]			
Estimates	6,762	9,734	3,530
Upper 95% limit	7,571	10,109	3,802
Lower 95% limit	6,077	9,359	3,258
Fishery Officers[c]			
Estimates	15,300	27,560	20,258
Snootli Hatchery[c]			
Estimates	19,600	26,800	21,600
Tower Counts[c]			
Estimates	5,912	7,726	2,772

[a] Includes males and females only.

[b] Includes males, females and jacks in 1984; includes males and females only in 1985 and 1986.

[c] From Appendices 25 to 28.

were collected in this study. Tagging mortality results in an overestimate of the population due to a decrease in the number of tag recoveries. An alternative to gillnetting would be seining, which might provide a less stressful method of capturing fish and a lower risk of handling mortality. The use of opercular punch holes as secondary marks to evaluate tag loss for purposes of Petersen calculations should be continued. However, punches should be applied to all fish tagged, and no punched fish should be released without tags. Tag loss could then be calculated accurately using the number of punch recoveries as the expected number of tag recoveries, rather than calculating the expected number of tag recoveries as was done in this study.

Comparison of Population Estimates

According to the Jolly-Seber estimates, the highest escapement of the three years of this study was in 1985, the second highest escapement was in 1984, and the lowest escapement was in 1986 These results are corroborated by the trend shown by the Snootli hatchery estimates and tower counts, but the fishery officer estimates indicate that the escapement in 1986 was higher than that in 1984 (Table 30, Appendix 25). The latter results were obtained independently of this study.

The Jolly-Seber estimates were consistently lower than other estimates of the Atnarko escapement in each year (Table 30). In 1986, the Petersen estimate was approximately four times as high as the Jolly-Seber estimate, although the confidence intervals of the two estimates overlap. The Jolly-Seber estimates were 17% to 40% of the average of the fishery officer and hatchery estimates. Studies on the Somass River (Shardlow et al. 1986) and the Harrison River (K. Wilson, Biologist, Department of Fisheries and Oceans, 555 West Hastings Street, Vancouver, B.C., pers. comm., 1987) found that fishery officer estimates were generally lower than the estimates produced by other methods, so the difference between the Jolly-Seber estimate and the fishery officer estimates on the Atnarko River may be greater than suggested by these results. The tower counts, which represent counts of fish for only a portion of the chinook run, (ignoring both early and late portions of the run) were 78.5% to 87.4% of the Jolly-Seber estimates (Table 30).

Other Sources of Bias

In 1984, the upper region of the Atnarko River from the confluence of the Hotnarko River to the outflow from Stillwater Lake was not sampled in the Jolly-Seber study, (approximately 10-20% of the river area sampled in 1985 and 1986), leading to a potential underestimate relative to the estimates in 1985 and 1986. A source of variation in the Jolly-Seber estimates was caused by inconsistencies in the data as indicated by the recovery in some sampling periods in 1985 and 1986 of a greater number of carcasses than were tagged. Errors in the raw data may have caused over- or underestimation of the escapements.

One potential source of bias in both the Petersen and Jolly-Seber estimates was that recognition of tags and opercular punch holes may have been less than 100%. The rate of missed punches was approximately 10% on the Harrison River (K. Wilson, pers. comm., 1987) and approximately 10% of a known group of spaghetti tags in the Somass River were undetected (Shardlow et al. 1986). We were not able to test for this

source of bias in this study, but in future studies, repitches of carcasses should be conducted to determine the proportion of missed tags and punches such that the tag recovery rate could be corrected by this factor.

One factor which could have produced a serious downward bias in the Jolly-Seber estimates is the incomplete mixing of marked carcasses with the rest of the carcass population. In all three years, tagged carcasses were replaced from where they were sampled. This procedure may have tended to prevent mixing with the rest of the carcass population. If this were the case, then the tagged carcasses would have a relatively high probability of being found again and sampled, and the overall population would be underestimated. Sykes and Botsford (1986) placed marked carcasses back in the free-flowing portion of the stream in their study and cited the exact replacement of carcasses as being a potential cause of bias.

Another potential source of downward bias in the Jolly-Seber estimates was that large portions of the carcass populations may not have been tagged, for example washed out carcasses and carcasses in deep pools. Unmarked carcasses may have been missed by the Jolly-Seber program by either being rapidly washed out of the system without ever becoming available to sampling, or by being washed into deep pools where sampling was less effective and where they may have become rapidly silted over and inaccessible. Although there is some degree of exchange between the populations of carcasses in deep pools and shallow bar areas, most of the tagging and sampling took place in shallow bar areas, hence a downward bias would result unless the exchange between the populations was complete. Exclusion of portions of the carcass population in tagging and incomplete mixing of tagged and untagged carcasses may have been an important source of downward bias in the Jolly-Seber estimates. The low tagged to untagged ratio at the carcass weirs in 1985 relative to the dead recovery (χ^2=74.22, df=1, $p<.001$) strongly suggests that this was a major source of downward bias in the Jolly-Seber estimates.

In 1984, there were two periods of heavy rainfall that created problems for the field crews. Rainfall on September 16 reduced visibility in the river for at least seven days, and surveys of certain areas of the river were curtailed while the stream flow was high (Fig. 2). Heavy rainfall and high water on October 6 prevented further surveys of the river until October 21. In 1985, increased stream flow resulted from rainfall events on October 15 and October 17 to 23. These events occurred in the latter part of the enumeration programs, and may not have affected the Jolly-Seber estimate (Fig. 2). Although increased stream flow adversely affected the efficiency of field crews, increased flow may have promoted greater mixing of tagged and untagged carcasses during these periods. Increased rates of stream flow probably increased the rate of washout of carcasses, but would have biased the population estimates only if tag rates were altered. However, tagged and untagged fish were most likely washed out of the system at the same rates as in lower stream flow periods. Simulations have shown that carcass washout does not seriously bias Jolly-Seber population estimates (Webb 1988).

In summary, Jolly-Seber estimates probably underestimated the Atnarko chinook escapement by as much as 75%, based on the potential

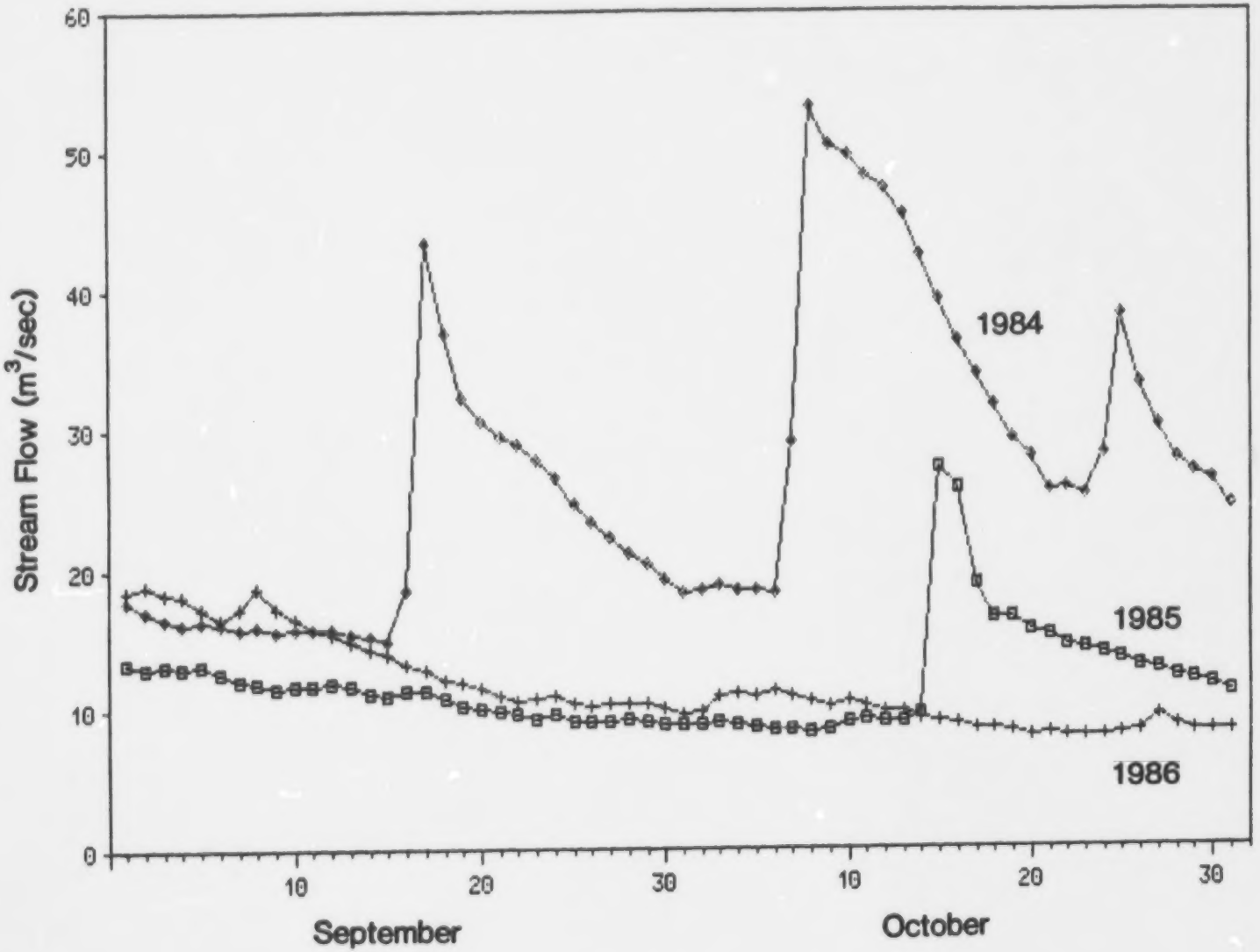

Figure 2. Stream flow of the Atnarko River, 1984-1986. Data from Water Survey of Canada (Station 08FB006 at mouth of Atnarko River).

sources of bias discussed above and acceptance of the 1986 Petersen estimate as being the more accurate method of population estimation despite the wide confidence limits on the 1986 estimate.

AGE, LENGTH AND SEX COMPOSITION

The Atnarko River chinook escapement in 1985 and 1986 was composed of mainly 4 and 5 year old fish which spent at least one full year in freshwater (sub 2's). In 1985 and 1986, males and females were of approximately the same age composition, but in 1985, females were slightly older than males. There was no bias in the readability of scales for age determination with age of fish (Kolmogorov-Smirnov tests, $p>.05$).

The 1985 and 1986 population estimates and the hatchery contribution to the escapements estimated from coded wire tag analyses were allocated to age groups according to the age compositions of 1985 and 1986 spawners determined from scale analyses.

Dorsal fin rays, vertebrae, and scales from the caudal area are currently being studied for their reliability for aging of chinook (Y. Yole, (Retired) Senior Fish Morphology Technician, Department of Fisheries and Oceans, 555 West Hastings Street, Vancouver, B.C., pers. comm., 1988) and may be used for more accurate age determinations in future programs.

CODED WIRE TAGGING AND RECOVERY

Accurate adipose clip rates are important data in the accurate estimation of the escapement of coded wire tagged fish. In this study, adipose clip rates were significantly higher in the broodstock collection and live tagging programs than in the dead recovery in both 1985 and 1986 (χ^2 tests, $p<.001$). Possible reasons for this discrepancy are that different criteria were used by observers to identify adipose clips, adipose clipped fish were selectively removed in the broodstock collection and live tagging programs, and/or decomposition of adipose clipped carcasses prior to dead recovery. In future programs, an estimate of observer biases in identification of adipose clips in both the broodstock collection and dead recovery programs should be incorporated into the study design. Selectively removing adipose clipped fish during broodstock collection and live tagging reduced, to a small extent, the adipose clip rate in the dead recovery such that escapement of adipose clips could have been underestimated. Nineteen female but no male adipose clipped fish were removed from the live tagging samples, and one live tagged and adipose clipped females was subsequently killed for eggtake. Decomposition and mutilation of adipose-clipped carcasses by bears prior to dead recovery are very probable causes of lower mark rates in dead recoveries in the Atnarko River.

Some other important potential sources of bias in the estimation of the escapement of coded wire tagged fish include the following:

1) The distribution of adipose clipped fish may be patchy so that if sampling was not uniform a significant bias may be introduced;

2) A low number of recoveries of adipose clips and decoded CWTs may make the precision of the estimates so low as to be of relatively little value; and

3) The sample of heads obtained for the decoding of CWTs may not be a random sample from the tagged population and might contain a bias due to size selectivity or other factors.

Patchiness in the distribution of adipose clipped fish in the Atnarko River was not assessed directly, but the broodstock collection, live tagging, and dead recovery programs were designed to allocate effort evenly among the reaches of the upper and lower river areas (Appendices 1 to 7). It is likely that patchiness of the distribution did not seriously bias the estimates.

We have not formally estimated the level of precision of the estimates of escapement of adipose clipped fish and individual tag codes since potential sources of bias can render these misleading. One approximation to the level of precision of the coded wire tag estimates can be obtained by examining confidence limits for the number of adipose clips and coded wire tag recoveries on which a given estimate was based. These confidence limits, based on a Poisson distribution, are shown in Table 29.

Hatchery released fish comprised an estimated 0.66% and 1.34% of the escapements in 1985 and 1986, respectively. To simplify analyses of hatchery stocks, sampling for coded wire tags should be conducted in a consistent manner in the tagging and dead pitch programs. In addition, sampling of adipose clipped fish should not be selective in any way (e.g. selectively removing certain sizes of adipose clipped females for broodstock collection and coded wire tag analysis).

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APPENDICES

Appendix 1. Petersen live tagging effort (number of fish sampled) on chinook salmon in the Atnarko River, 1986.

Tagging reach[a]	Sampling date: September 4	5	6	7	8	9	10	11	12	13	14	15	Total
Reach 1, Subreach 1													
Male	2												2
Female	4												4
Jack	0												0
Reach 1, Subreach 2													
Male	2		9	6		13	18	19					67
Female	1	2	18	12		10	15	17					75
Jack	0	0	0	0		0	0	0					0
Reach 2, Subreach 1													
Male		13			6		8	14	21	17		5	84
Female		3			14		14	11	16	45		3	106
Jack		0			0		0	0	0	1		0	1
Reach 2, Subreach 2													
Male			8		18	4	18		10		21	7	86
Female			4		34	9	25		17		23	4	116
Jack			0		0	0	0		0		0	0	0
Reach 3, Subreach 1													
Male						5	5				5	14	29
Female						24	7				1	13	45
Jack						0	0				0	0	0
Reach 3, Subreach 2													
Male						10		19	12		19	18	78
Female						16		35	9		22	9	91
Jack						0		0	0		0	0	0
Reach 4, Subreach 1													
Male		0						8	5	2		28	43
Female		9						12	4	6		27	58
Jack		0						0	0	0		1	1
Reach 5, Subreach 1													
Male	0	0	0		10			19		3		8	40
Female	9	10	3		12			25		1		12	72
Jack	0	0	0		0			0		0		1	1
Reach 5, Subreach 2													
Male		9	16		6	30	20						81
Female		20	18		10	43	50						141
Jack		0	0		0	0	0						0
Total	18	66	76	18	110	164	180	179	94	75	91	150	1,221

[a] Upper river: Reach 1, Subreach 1 (Stillwater Lake to Hotnarko Creek); Reach 1, Subreach 2 (Hotnarko Creek to Line Cabin); Reach 2, Subreach 1 (Line Cabin to Birch Run); Reach 2, Subreach 2 (Birch Run to Josephines); Reach 3, Subreach 1 (Josephines to Padgetts); Reach 3, Subreach 2 (Young Creek to Parks Branch); Lower River: Reach 4, Subreach 1 (Parks Branch to Elbow Pool); Reach 5, Subreach 1 (Elbow Pool to Belarko); Reach 5, Subreach 2 (Belarko to Fisheries Pool).

Appendix 2. Jolly-Seber carcass tagging and recovery effort (number of fish sampled) on chinook salmon in the Atnarko River by sampling period, 1985.

Reach[a]	Sampling period[b]									Total
	1	2	3	4	5	6	7	8	9	
Tagging										
Reach 1										
Males	18	24	186	210	200	176	137	40[c]	0	991
Females	31	26	145	230	219	202	135	48[c]	0	1,036
Jacks	2	4	27	21	67	72	14	1[c]	0	208
Reach 2										
Males	3	44	72	165	208	136	117	41[c]	0	786
Females	6	50	82	210	201	188	119	77[c]	0	933
Jacks	0	2	5	27	30	70	16	1[c]	0	151
Reach 3										
Males	16	30	62	289	251	209	155	73	0	1,085
Females	21	64	99	198	201	306	156	114	0	1,159
Jacks	0	3	3	17	40	102	25	7[c]	0	197
Reach 4										
Males	0	4	27	41	77	106	93	78	0	426
Females	1	11	32	61	180	167	122	147	0	721
Jacks	0	0	0	1	21	23	13	10[c]	0	68
Tagging total										7,761
Tag recoveries										
Reach 1										
Males	0	3	22	74	106	115	121	44	0	485
Females	0	8	32	88	144	105	153	44	0	574
Jacks	0	0	2	9	30	26	15	0	0	82
Reach 2										
Males	0	2	8	75	118	158	64	48	0	473
Females	0	10	7	91	165	187	142	76	0	678
Jacks	0	0	0	1	12	34	8	3	0	58
Reach 3										
Males	0	5	12	49	132	156	114	75	19	562
Females	0	7	22	93	174	195	201	116	20	828
Jacks	0	0	0	1	4	30	11	4	0	50

continued

Appendix 2 (continued)

Reach 4										
Males	0	0	5	11	24	65	53	52	37	247
Females	0	0	4	13	52	85	93	96	77	420
Jacks	0	0	0	0	6	10	2	0	0	18
Recovery total										4,474

[a] Reaches 1 and 2 were in the upper river, reaches 3 and 4 were in the lower river (Table 1).

[b] Sampling period 1 = Sept. 12-15; 2 = Sept. 16-19; 3 = Sept. 20-23; 4 = Sept. 24-27; 5 = Sept. 28-Oct. 1; 6 = Oct. 2-5; 7 = Oct. 6-9; 8 = Oct. 10-13; 9 = Oct. 14-17.

[c] 225 tagged fish shown here were not included in Jolly-Seber calculations (Table 6) as sampling period 8 was the final sampling period for some strata.

Appendix 3. Jolly-Seber carcass tagging effort (number of fish sampled) on chinook salmon in the Atnarko River, 1986.

Tagging reach[a]	Sampling date: September 16	17	18	19	21	22	23	24	25	28	29	30	October 1	2	5	6	7	8	9	Total
Reach 1																				
Male				39					118					171					74	402
Female				79					178					238					112	607
Jack				2					13					18					6	39
Unknown				1					0					3					0	4
Reach 2																				
Male			5	10				92					137					62		306
Female			20	21				200					191					139		571
Jack			0	0				2					16					4		22
Unknown			0	0				2					1					3		6
Reach 3																				
Male		11					60				179					151				401
Female		59					207				281					203				750
Jack		0					6				21					6				33
Unknown		0					0				1					2				3
Reach 4																				
Male	1				0	29				101					145					276
Female	6				7	85				291					222					611
Jack	0				0	2				8					4					14
Unknown	0				0	0				0					2					2
Reach 5																				
Male										44					75					119
Female										128					116					244
Jack										3					8					11
Unknown										0					5					5
Total	7	70	25	152	7	116	273	296	309	175	400	482	345	430	204	373	362	208	192	4,426

[a]Reaches 1 to 3 were in the upper river, Reaches 4 and 5 were in the lower river (Table 1).

Appendix 4. Petersen recovery effort (number of fish sampled) on chinook salmon in the Atnarko River, 1986.

Tagging reach[a]	Sampling date: September 15	17	18	19	21	22	23	24	25	28	29	30	October 1	2	5	6	7	8	9	12	13	14	Total
Reach 1, Subreach 1																							
Male				0	1				1	1					1								4
Female				1	3				0	3					1								8
Jack				0	0				0	0					0								0
Reach 1, Subreach 2																							
Male				0		3				2					1					0	0		6
Female				1		2				2					1					1	1		8
Jack				0		0				0					0					0	0		0
Reach 2, Subreach 1																							
Male		1	0			1	3				3					1							9
Female		2	3			7	8				13					4							37
Jack		0	0			0	0				0					0							0
Reach 2, Subreach 2																							
Male		1					0	0			1	1				1							4
Female		5					5	1			5	5				0							21
Jack		0					0	0			0	0				0							0
Reach 3, Subreach 1																							
Male							4					3					0					1	8
Female							14					6					1					0	21
Jack							0					0					0					0	0
Reach 3, Subreach 2																							
Male			1					3				4					0						8
Female			0					6				3					3						12
Jack			0					0				0					0						0
Reach 4, Subreach 1																							
Male				0				8	0			2	1					1					12
Female				1				8	3			2	6					0					20
Jack				0				0	0			0	0					0					0
Reach 5, Subreach 1																							
Male	0			2					2	0				5									9
Female	1			7					7	1				3									19
Jack	0			0					0	0				0									0
Reach 5, Subreach 2																							
Male														1					0				1
Female														2					1				3
Jack														0					0				0
Total	1	9	4	12	4	13	34	26	13	9	22	26	7	11	4	6	4	1	1	1	1	1	210

[a] Upper river: Reach 1, Subreach 1 (Stillwater Lake to Hotnarko Creek); Reach 1, Subreach 2 (Hotnarko Creek to Line Cabin); Reach 2, Subreach 1 (Line Cabin to Birch Run); Reach 2, Subreach 2 (Birch Run to Josephines); Reach 3, Subreach 1 (Josephines to Padgetts); Reach 3, Subreach 2 (Young Creek to Parks Branch); Lower River: Reach 4, Subreach 1 (Parks Branch to Elbow Pool); Reach 5, Subreach 1 (Elbow Pool to Belarko); Reach 5, Subreach 1 (Belarko to Fisheries Pool).

Appendix 5. Jolly-Seber carcass recovery effort (number of fish sampled) on chinook salmon in the Atnarko River, 1986.

Tagging reach[a]	Sampling date: September 21	22	23	24	25	28	29	30	October 1	2	5	6	7	8	9	12[b] T	12[b] NT	13 T	13 NT	14 T	14 NT	15 T	15 NT	16 T	16 NT	Total
Reach 1																										
Male					25					19					40							1		16	24	125
Female					33					46					68			1						34	19	201
Jack					0					0					3									3	3	9
Unknown					1					0					0									0	1	2
Reach 2																										
Male				6					39				57									22	16			140
Female				17					61				132									61	29			300
Jack				0					3				5									2	1			11
Unknown				0					2				2									1	1			6
Reach 3																										
Male			5					46				117								77	54					299
Female			27					121				185								126	91					550
Jack			0					1				8								1	0					10
Unknown			0					0				1								1	1					3
Reach 4																										
Male	0	2					23				67							75	40							207
Female	2	4					93				180							139	116							534
Jack	0	0					1				2							0	3							6
Unknown	0	0					0				0							1	10							11
Reach 5																										
Male						6				16					5	40	31									98
Female						24				71					14	61	76									246
Jack						0				0					1	3	1									5
Unknown						0				0					0	3	5									8
Total	2	6	32	23	59	30	117	168	105	65	87	249	311	196	131	107	113	216	169	205	146	87	47	53	47	2,771

[a]Reaches 1 to 3 were in the upper river, Reaches 4 and 5 were in the lower river (Table 1).

[b]Final sampling period was from October 12-16: T = tag recovery; NT = recovered fish was untagged, no tag was applied.

Appendix 6. Petersen live tagging and recapture locations of Atnarko River chinook salmon, 1986.

Tagging location[a]		Recapture reach								
Reach	Subreach	1	2	3	4	5	6	7	8	9
Males										
1	1									
1	2	2		3	1	2			1	
2	1	1	3	3	1	2		1		
2	2		2	3	1	1	1	1		
3	1		1	1		2		1		
3	2					1	7	3		
4	1			1			4	1		
5	1						1	3		
5	2						1	4	1	
Females										
1	1	1								
1	2	5	3	11						
2	1	1	1	10	9	6				
2	2		1	6	8	11	1	1		
3	1		1	6	2	2				
3	2			4	2	2	11	4		
4	1		1	1				9	6	1
5	1	1	1					5	2	
5	2							1	10	2
Jacks[b]										

[a] Upper river: Reach 1, Subreach 1 (Stillwater Lake to Hotnarko Creek); Reach 1, Subreach 2 (Hotnarko Creek to Line Cabin); Reach 2, Subreach 1 (Line Cabin to Birch Run); Reach 2, Subreach 2 (Birch Run to Josephines); Reach 3, Subreach 1 (Josephines to Padgetts); Reach 3, Subreach 2 (Young Creek to Parks Branch); Lower River: Reach 4, Subreach 1 (Parks Branch to Elbow Pool); Reach 5, Subreach 1 (Elbow Pool to Belarko); Reach 5, Subreach 2 (Belarko to Fisheries Pool).

[b] There were no tagged jacks recovered.

Appendix 7. Jolly-Seber carcass tagging and recapture locations of Atnarko River chinook salmon, 1986.

	Recovery reach				
Tagging reach[a]	1	2	3	4	5
Male					
1	105	15			
2	12	114	38		
3			211	21	
4			1	147	7
5				3	55
Female					
1	182	35		1	
2	3	238	65	1	
3		11	368	100	1
4			2	315	25
5	5	1		8	132
Jack					
1	6	2			
2		8			
3			10	1	
4				2	
5					3
Unknown Sex					
1	1[b]	1[c]			
2		4[d]			
3			2[e]		
4					
5				1[f]	3[g]

[a] Reaches 1 to 3 were in the upper river, Reaches 4 and 5 were in the lower river (Table 1).

[b] Tag code 2798

[c] Tag code 5360

[d] Tag code 3430, 3454, 5276, 6691

[e] Tag code 4586, 6640

[f] Tag code 6025

[g] Tag code 5486, 5496, 5498

Appendix 8

DETAILED RESULTS OF THE JOLLY-SEBER CALCULATIONS

In Appendices 9 to 24 we present the detailed results of the Jolly-Seber calculations used to produce the estimates presented in the main text. A table for each dataset represents the analysis of the input data using the appropriate Jolly-Seber equations described in Webb (1988). The six columns of results represent for each sampling period of the population:

LAMBDA - the mean residence time of carcasses in days;

BETA - the total number of marked carcasses in the system immediately prior to sampling;

Di - the total number of carcasses added to the system between times I and I+1 including those washed out prior to I+1;

Ni - the estimated carcass pool size prior to the Ith sample;

Si - the survival rate of carcasses (i.e. retention in the system) from I to I+1; and

Bi - the number of carcasses added between I and I+1 and remaining to I+1.

The most important result in these tables is the sum of the entries to the population (Di) which is the estimated escapement.

Appendix 9. Jolly-Seber reconstruction for the male chinook salmon escapement to the upper Atnarko River, 1984. In this study, recovered carcasses with tags were replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	2.466	.0	4.4	1.6	.667	3.6
2	99.499	1.3	23.5	4.7	.990	23.4
3	4.876	7.0	164.3	28.0	.815	148.3
4	99.499	24.4	50.6	171.1	.990	50.3
5	2.138	59.6	71.9	219.7	.626	56.9
6	2.342	86.8	163.1	194.5	.653	131.7
7	2.651	119.3	135.6	258.6	.686	112.3
8	99.499	167.5	182.5	289.6	.990	181.6
9	.297	305.0	.0	468.3	.035	-.3
10	.000	14.5	.0	15.9	.000	.0

Escapement estimate = 731
Total carcasss tagged = 585
Total carcasses pitched = 1,199

Appendix 10. Jolly-Seber reconstruction for the male chinook salmon escapement to the lower Atnarko River, 1984. In this study, recovered carcasses with tags were replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	-1.558	.0	5.0	4.3	1.900	6.9
2	1.731	3.8	12.5	15.2	.561	9.3
3	1.099	5.5	45.8	17.9	.403	29.0
4	1.127	5.4	630.4	36.2	.412	404.6
5	4.260	15.8	-36.4	419.5	.791	-32.4
6	2.379	83.7	78.4	299.3	.657	63.5
7	4.111	137.1	198.8	60.2	.784	176.0
8	2.194	175.7	44.3	380.0	.634	35.3
9	2.677	200.1	55.3	276.2	.688	45.9
10	.000	177.0	.0	236.0	.000	.0

Escapement estimate = 1,033
Total carcasses tagged = 548
Total carcasses pitched = 1,208

Appendix 11. Jolly-Seber reconstruction for the female chinook salmon escapement to the upper Atnarko River, 1984. In this study, recovered carcasses with tags were replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	-.520	.0	29.4	28.8	6.833	76.7
2	.561	13.7	22.1	273.3	.168	9.1
3	-4.638	5.3	558.0	55.1	1.241	621.5
4	.522	37.6	446.6	689.9	.147	171.3
5	-1.964	18.2	418.9	272.7	1.664	540.3
6	.841	133.4	680.2	994.1	.304	375.2
7	3.296	90.8	206.6	677.7	.738	177.5
8	6.691	191.1	359.8	77.9	.861	333.9
9	5.133	340.2	187.7	917.6	.823	170.3
10	.298	452.0	7.7	925.5	.035	1.4
11	.000	21.5	.0	33.8	.000	.0

Escapement estimate = 2,923
Total carcasses tagged = 1,102
Total carcasses pitched = 2,416

Appendix 12. Jolly-Seber reconstruction for the female chinook salmon escapement to the lower Atnarko River, 1984. In this study, recovered carcasses with tags were replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	.963	.0	14.5	9.0	.354	8.6
2	.977	4.6	44.3	11.8	.359	26.6
3	1.300	5.6	95.8	30.8	.463	65.3
4	1.570	18.4	474.1	79.5	.529	344.8
5	3.444	46.7	72.7	386.8	.748	62.9
6	-78.676	128.5	160.9	352.2	1.013	162.0
7	3.009	281.0	300.2	518.7	.717	254.2
8	3.099	321.3	76.3	626.2	.724	65.0
9	2.493	400.0	71.5	518.5	.670	58.5
10	.000	342.1	.0	405.6	.000	.0

Escapement estimate = 1,321
Total carcasses tagged = 911
Total carcasses pitched = 2,215

Appendix 13. Jolly-Seber reconstruction for the jack chinook salmon escapement to the upper Atnarko River, 1984. In this study, recovered carcasses with tags were replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	0.000	.0	1.5	1.5	1.000	1.5
2	8.490	1.0	42.4	3.0	.889	40.0
3	16.162	2.7	55.6	42.7	.940	53.9
4	.866	15.7	36.1	94.0	.315	20.2
5	1.510	8.1	39.4	49.9	.516	28.3
6	15.269	19.6	83.4	54.0	.937	80.7
7	-4.066	44.6	171.9	131.3	.279	194.4
8	.185	142.7	1.5	362.4	.004	.1
9	.143	1.0	1.2	1.7	.001	.0
10	.000	.0	.0	.0	.000	.0

Escapement estimate = 430
Total carcasses tagged = 272
Total carcasses pitched = 437

Appendix 14. Jolly-Seber reconstruction for the jack chinook salmon escapement to the lower Atnarko River, 1984. In this study, recovered carcasses with tags were replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	1.443	.0	5.3	2.5	.500	3.7
2	.621	1.0	10.1	5.0	.200	4.5
3	.455	1.0	52.2	5.5	.111	17.4
4	2.368	1.0	94.7	18.0	.656	76.7
5	3.133	11.8	34.1	88.5	.727	29.1
6	22.476	27.5	183.6	93.4	.956	179.5
7	2.735	49.2	-65.1	268.9	.694	-54.2
8	1.411	73.0	9.7	132.3	.492	6.8
9	.000	48.7	.0	72.0	.000	.0

Escapement estimate = 324
Total carcasses tagged = 163
Total carcasses pitched = 253

Appendix 15. Jolly-Seber reconstruction for the male chinook salmon escapement to the upper Atnarko River, 1985. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	1.359	.0	61.2	21.0	.479	42.3
2	2.048	7.7	134.4	52.4	.614	105.3
3	-13.598	22.5	507.3	133.7	1.076	526.3
4	2.313	101.7	448.2	652.0	.649	361.1
5	2.841	241.2	344.1	745.2	.703	288.6
6	3.373	290.6	405.6	703.0	.743	349.7
7	1.285	285.9	175.4	708.1	.459	118.8
8	1.046	168.5	96.1	367.4	.384	59.6
9	.000	74.0	.0	152.0	.000	.0

Escapement estimate = 2,200
Total carcasses tagged = 1,511
Total carcasses pitched = 2,380

Appendix 16. Jolly-Seber reconstruction for the male chinook, salmon escapement to the lower Atnarko River, 1985. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	1.180	.0	148.7	31.9	.429	97.3
2	4.629	9.0	507.4	111.0	.806	455.4
3	2.578	58.0	403.8	540.8	.679	332.6
4	3.888	194.1	572.9	679.2	.773	503.8
5	2.451	324.8	324.9	913.8	.665	264.9
6	5.395	338.3	402.9	723.6	.831	367.2
7	1.1107	313.5	103.7	741.6	.406	66.1
8	.000	155.4	.0	292.3	.000	.0

Escapement estimate = 2,507
Total carcasses tagged = 1,696
Total carcasses pitched = 2,735

Appendix 17. Jolly-Seber reconstruction for the female chinook salmon escapement to the upper Atnarko River, 1985. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	4.370	.0	170.0	48.7	.795	151.6
2	1.758	17.5	241.5	190.3	.566	181.7
3	5.838	48.4	245.5	283.3	.843	225.4
4	-20.721	129.3	430.1	442.1	1.049	440.6
5	4.852	296.2	580.4	793.4	.814	523.5
6	4.698	367.2	514.9	985.2	.808	462.9
7	1.881	452.8	255.3	1033.0	.588	195.7
8	1.043	256.7	117.1	571.2	.383	72.5
9	.000	117.1	.0	210.1	.000	.0

Escapement estimate = 2,605
Total carcasses tagged = 1,880
Total carcasses pitched = 3,309

Appendix 18. Jolly-Seber reconstruction for the female chinook salmon escapement to the lower Atnarko River, 1985. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	3.991	.0	113.2	56.7	.778	99.9
2	3.207	28.8	387.9	144.0	.732	331.9
3	-63.206	63.5	485.1	424.2	1.016	488.9
4	4.541	255.6	461.4	880.3	.802	413.3
5	2.428	414.5	454.0	976.0	.662	369.5
6	3.959	348.1	272.8	811.3	.777	240.4
7	1.290	346.5	186.6	643.8	.461	126.6
8	.000	140.7	.0	287.3	.000	.0

Escapement estimate = 2,422
Total carcasses tagged = 1,844
Total carcasses pitched = 3,221

Appendix 19. Jolly-Seber reconstruction for the jack chinook salmon escapement to the upper Atnarko River, 1985. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	.910	.0	4.6	4.0	.333	2.7
2	-1.036	1.0	123.1	4.0	2.625	199.5
3	.444	10.5	154.1	210.0	.105	50.0
4	.365	3.0	637.8	72.0	.065	162.0
5	.241	4.0	396.9	166.0	.016	50.0
6	.393	2.0	65.5	52.0	.078	18.4
7	.000	3.1	.0	21.4	.000	.0

Escapement estimate = 1,385
Total carcasses tagged = 248
Total carcasses pitched = 333

Appendix 20. Jolly-Seber reconstruction for the jack chinook salmon escapement to the lower Atnarko River, 1985. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	1.443	.0	8.2	2.3	.500	5.8
2	-1.045	1.0	120.5	7.0	2.604	194.5
3	1.158	18.2	31.2	212.7	.422	20.2
4	18.414	20.3	88.4	109.1	.947	86.1
5	2.508	55.3	187.6	179.9	.671	153.7
6	.534	74.0	64.6	246.3	.154	25.3
7	.432	24.0	6.5	54.0	.099	2.0
8	.000	3.1	.0	5.1	.000	.0

Escapement estimate = 507
Total carcasses tagged = 357
Total carcasses pitched = 499

Appendix 21. Jolly-Seber reconstruction for the male chinook salmon escapement to the upper Atnarko River, 1986. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	2.596	.0	130.5	16.8	.680	107.6
2	2.850	9.5	276.1	119.1	.704	231.7
3	2.917	66.5	138.1	310.6	.710	116.4
4	12.087	144.5	-54.3	301.3	.921	-52.1
5	.000	145.0	.0	97.3	.000	.0

Escapement estimate = 509
Total carcasses tagged = 445
Total carcasses pitched = 735

Appendix 22. Jolly-Seber reconstruction for the male chinook, salmon escapement to the lower Atnarko River, 1986. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	3.730	.0	230.3	65.0	.765	201.4
2	1.683	39.8	467.4	251.1	.552	347.3
3	1.593	98.7	25.8	468.8	.534	18.8
4	-1.692	176.5	-17.8	224.8	1.806	-23.9
5	.000	94.8	.0	73.2	.000	.0

Escapement estimate = 778
Total carcasses tagged = 584
Total carcasses pitched = 940

Appendix 23. Jolly-Seber reconstruction for the female chinook salmon escapement to the upper Atnarko River, 1986. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	3.144	.0	429.8	96.4	.728	366.6
2	2.736	49.5	398.4	436.8	.694	331.9
3	12.048	200.9	65.3	611.4	.920	62.7
4	-1.088	361.6	-12.0	457.8	2.507	-19.1
5	.000	254.6	.0	241.2	.000	.0

Escapement estimate = 992
Total carcasses tagged = 810
Total carcasses pitched = 1,613

Appendix 24. Jolly-Seber reconstruction for the female chinook salmon escapement to the lower Atnarko River, 1986. In this study, recovered carcasses were not replaced.

Sampling period	LAMBDA	BETA	Di	Ni	Si	Bi
1	1.663	.0	533.0	150.4	.548	394.6
2	1.936	64.1	580.7	477.1	.597	448.5
3	2.652	201.1	-13.1	703.9	.686	-10.9
4	-.940	307.3	-50.6	360.1	2.897	-86.1
5	.000	180.6	.0	99.6	.000	.0

Escapement estimate = 1,251
Total carcasses tagged = 900
Total carcasses pitched = 1,504

Appendix 25

ALTERNATIVE ESCAPEMENT ESTIMATES

In addition to the key stream program on the Atnarko River, chinook escapement estimation was performed by three other groups: Department of Fisheries and Oceans fishery officers, the Central Coast Fishermen's Protective Association (tower counts), and Snootli Creek Hatchery. These estimates are described and presented here for purposes of comparison with the Jolly-Seber and Petersen estimates presented in this report. However, it should be understood that these alternative estimates may not be free of bias and may not be independent of one another. In particular, the accuracy of tower counts estimates was biased by the restricted sampling period, and Snootli Creek Hatchery estimates were not independent of fishery officer estimates since they were calibrated to the 1981 fishery officer estimates.

Fishery Officer Estimates

The fishery officer estimates of chinook escapement to the study area of the Atnarko River were based on an extrapolation of peak fish counts (live plus carcass count) obtained in foot surveys or boat drifts of three standardized sections of the river. These sections represented a known fraction of the length of the Atnarko River from the Talchako confluence to the lower end of Stillwater Lake. The three sections were:

1 - from the outflow of Stillwater Lake to immediately above the Hotnarko River (2.4 km), counted by foot surveys;

2 - from immediately above Sugar Creek Camp (Line Cabin) to immediately above Young Creek (4.7 km), counted by boat drifts; and

3 - from Belarko to the Talchako River confluence (3.1 km), counted by boat drifts and foot surveys.

Each section was surveyed by boat drift and/or foot surveys three or four times during the spawning period. The counts from these surveys were adjusted based on the stream inspectors' best estimates of the numbers of fish in areas of the river outside the survey areas listed above, and on fish missed prior to and after these counts are done. In addition, counts were sometimes adjusted (or in some cases eliminated) based on the estimated effect of poor viewing conditions such as water turbidity, wind conditions, or low light levels. The magnitude of these adjustments varied from zero to an increase of more than 120%.

The adjusted peak count was expanded to an estimate of the total escapement by multiplying it by the ratio of the total length of the river (32.8 km) to the length surveyed (10.2 km). This method of calculation assumed equal density of spawners along the river. The adjusted peak count for each section normally occurred in the same survey period; if one of these counts was missing, then a count from an adjacent survey period was used. An additional count of chinook was performed in the Upper Atnarko River (Knot Lake to Stillwater Lake) during the annual sockeye counts in late September; this count was also adjusted and added

to the total peak estimate for the Atnarko River. Counts of chinook in the spawning channel were not included in the estimates.

The fishery officer estimates of chinook escapement to the Atnarko River were 15,300 spawners in 1984, 27,560 spawners in 1985, and 20,258 spawners in 1986 (Appendix 26).

Tower Count Estimates

A tower used by the Central Coast Fishermen's Protective Association in collaboration with fishery officers to obtain direct counts of pink and chinook salmon was located on the Atnarko River approximately 1.6 km upstream from the confluence with the Talchako River. From the end of July to mid-September each year, direct counts were made of fish passing beneath the tower each day (Appendix 27). Counts were performed during every second hour of daylight for a total of six hours of counting each day. The counts were directed primarily at pink salmon; counts of chinook were not systematically collected, nor did the time span during which the tower was manned cover the entire period when chinook are moving into the Atnarko (J. Greenlee, pers. comm., 1987). Assuming that chinook migrated past the tower for 12 hours each day, escapement could be estimated by multiplying the tower counts by a factor of two. Tower count estimates of chinook escapement to the Atnarko River were 5,912 spawners in 1984, 7,726 spawners in 1985, and 2,772 spawners in 1986 (Appendix 27).

Escapement estimates from tower counts were probably underestimates since the counts did not span the entire migration run and fish may have migrated at night.

Snootli Creek Hatchery Estimates

Escapement was estimated by the Snootli Creek Hatchery staff by extrapolation from the catch per unit of effort (CPUE) in gillnet sets used to obtain spawners for brood stock. Gillnet sets were performed with a 21.3 m, 23 cm stretched mesh net. Approximately the same locations in the river were sampled each year. However, gillnetting effort gradually increased each year as the egg targets for the hatchery increased (from 50 females in 1982 to 400 females in 1986; R. Hilland, pers. comm., 1987).

This method was calibrated in 1981, a year of unusually low escapement, by comparing the catch per gillnet set with the escapement estimated by two helicopter surveys made that year by fishery officers and by direct counts made along the river. This method assumes that sampling of the run was unbiased with respect to timing and duration.

In 1981, the mean catch per set was 1.6 fish and the estimated escapement was 4,500. The escapement estimates for subsequent years were obtained by determining the ratio of the mean CPUE in each year to the mean CPUE in 1981, and multiplying by a factor of 4,500. The resulting estimate was rounded upwards slightly (0.56% in 1984, 0.63% in 1985, and 0.79% in 1986) to compensate for an underrepresentation of jacks in catches due to gillnet mesh size. The mean CPUE and resulting escapement estimates derived from this method for each year are shown in Appendix 28.

Appendix 26. Estimates of chinook salmon escapement to the Atnarko River based on methods used by fishery officers, 1984 - 1986.

Year	Escapement estimate[a]
1984	15,300
1985	27,560
1986	20,258

[a]Does not include spawners in the spawning channel.

Appendix 27. Estimates of chinook salmon escapement to the Atnarko River based on tower counts, 1984 - 1986.

Year	Counting dates		Count	Estimated escapement[a]
	Start	Finish		
1984	July 30	September 15	2,956	5,912
1985	July 28	September 20	3,863	7,726
1986	July 28	September 13	1,386	2,772

[a]Escapement was estimated by multiplying the tower count by a factor of two.

Appendix 28. Estimates of chinook salmon escapement to the Atnarko River based on methods used by the Snootli Creek Hatchery, 1984 - 1986.[a]

Year	Mean catch per set	Estimated escapement[b]
1984	6.93	19,600
1985	9.47	26,800
1986	7.62	21,600

[a]Data from R. Hilland, pers. comm., 1987.

[b]Estimates were adjusted slightly to account for the under-representation of jacks in the gillnet catches (see text for details).